ENERGY R&D

HOWDEN

PLASMA EXTENDED ARC REACTOR

REPORT REPARED FOR THE

ONTARIO MINISTRY OF ENERGY

BY

HOWDEN GROUP CANADA LIMITED

SCARBOROUGH, ONTARIO

MARCH 9, 1987

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Funding Support for this project was provided by the Ontario Ministry of Energy

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1.3 ABSTRACT

This project concerns processing of electric arc furnace dust (EAFD) in an environmentally safe manner employing the plasma extended arc reactor (PEAR). A one megawatt reactor was designed, built and operated based on information and operating results derived from a 100 KW unit at the University of Toronto. This near commercial size PEAR was energized on November 24, 1985.

A stable, controllable thermal plasma is obtained by injecting small amounts of argon into the electric arc zone. This is accomplished by passing the gas through hollow graphite electrodes.

From March to July 1986, the PEAR was run intermittently employing cast iron as the primary feed material. This was followed by feeding mixtures of mill scale and coke. During September and October 1986, controlled amounts of zinc and zinc oxide were added to the furnace feed. These preliminary furnace campaigns were aimed at checking out and/or modifying the reactor and its ancillaries.

Some of the components requiring attention and/or modifications included the feed system, the electrode assemblies, the refractory lining, the gas sampling system, the zinc splash condenser and the cross-over pipes connecting the PEAR with the cyclone and the condenser.

From November 1986 to February 1987, a total of 8 tons of briquets containing EAFD, reducing agent and fluxes were successfully processed. The resulting metal was cast iron, and the slag met the Ontario Regulation No.309 concerning leachable cadmium, lead, chromium and zinc.

As well, final stack emissions and air monitoring of personnel on a time averaged basis were within regulation standards.

The Project is continuing.

1.4 EXECUTIVE SUMMARY

This project concerns processing of electric arc furnace dust (EAFD) derived from mini steel mills which use automobile scrap as the primary raw material for making steel. This EAFD is a designated toxic material as it typically contains 2 to 3 percent lead along with traces of cadmium and up to 25 percent zinc.

The overall aim of this development and demonstration project is to convert the EAFD to environmentally stable materials. To accomplish this, the EAFD is blended with controlled quantities of carbon and fluxes for smelting and then fed in briquetted form to the plasma extended arc reactor (PEAR).

Operated at electric power levels of up to 1 megawatt, the hot plasma gases in the PEAR effect rapid heat up, melting and reaction of the feed constituents. The reaction products iron and slag are tapped intermittently while the resulting metallic zinc, lead and cadmium vapours are drawn off continuously and recovered down-stream in a molten bath of zinc. The furnace gases, rich in carbon monoxide, are burned down-stream of the zinc/lead condenser but ahead of the baghouse and stack.

Currently the toxic steel mill dust is being transported to landfill sites. However, the originator of the dust is liable for any damages as the toxic materials seep into the ground water and, thus, contaminate the environment. For this reason there is an urgent need to develop a process that converts this dust into environmentally safe components.

To-date, a total of 12 tons of cast iron, 5 tons of slag and 1 ton of lead/zinc were produced in the PEAR.

All slags produced were environmentally stable and leachable cadmium, chromium and lead were well within the Canadian and US regulations.

Also, final stack emissions and air monitoring of personnel on a time averaged basis were within regulations.

The project is continuing.

H.G. Brandstatter P.Eng.
Consultant, Howden Group Canada Limited

2.1 INTRODUCTION AND PURPOSE

The electric arc furnace dust (EAFD) is being generated at a rate of 1.5 to 2.0% of the steel production. The EAFD from the mini steel mills contains up to 25% zinc oxide, up to 2 to 3% lead oxide and small amounts of cadmium. These toxic constituents originate from galvanized and other lead and zinc bearing scrap used as furnace feed.

Approximately 75% of the EAFD generated in North America goes to landfill sites at costs ranging from US $ 50 to 200 per ton of EAFD. Due to more stringent Government regulations, the number of approved sites are decreasing. As a result disposal costs are expected to rise.

This research and development program is aimed at providing an on-site facility to convert EAFD into an environmentally stable slag. In addition, metallic iron is recovered as well as the lead and zinc values.

2.2 RATIONALE AND BACKGROUND

The PEAR concept and has been experimentally checked out at the Department of Metallurgy and Materials Science of the University of Toronto at a scale of 100 KW employing EAFD and other feed stocks. The results derived from these studies indicate that the PEAR system is technically feasible for processing EAFD. However, in these tests the resulting zinc values were recovered as oxides rather than as metallics.

2.3 TECHNICAL DESCRIPTION

2.3.1 DESCRIPTION OF THE PEAR SYSTEM

The PEAR system is located in the pilot plant of the Ontario Research Foundation.

The steel shell of the PEAR is 2.1 m in diameter and 2.5 m high. The refractory lining is 0.55 m thick. This leaves a useful reactor diameter of 1.0 m, a hearth area of 0.79 m2 and a furnace cavity of approximately 1.2 m3. The electrode assembly consists of three 130 mm diameter graphite electrodes which penetrate the sidewall of the furnace at an angle of 30o from the horizontal. Thus, the useful furnace volume below the electrode tips can accommodate an equivalent of approximately three tons of metal. A schematic diagram of the PEAR is shown in Figure 1.

Electrical power is supplied from a 2.5 MVA transformer equipped with four secondary voltage taps, ranging from 88 - 240 V.

The feed materials are fed by gravity through the roof by means of three feed chutes between adjacent electrodes.

The furnace gases and vapours exit the furnace through the side arm into a cyclone which removes flyash prior to entering the zinc splash condenser. This unit was designed by Imperial Smelting Processes Ltd. A portion of approximately four tons of molten zinc is agitated and the resulting zinc droplets capture the lead, zinc and cadmium vapours contained in the exit gases. The condenser has provisions for raking out dross, cooling the zinc bath as well as heating the bath by means of a number of gas burners.

The furnace gases, depleted of metal vapours, are burned prior to entering the baghouse. The cleaned gases are then discharged to the atmosphere via a short stack.

Figure 2 shows a line diagram of the PEAR system and Figure 3 a process flow diagram. Pictures 1 and 2 provide an overview of the facility in more detail.

Molten iron and slag are tapped from the hearth into refractory lined receivers.

The temperature profile of the furnace top, sides and bottom, as well as gas exit, cyclone and condenser is controlled and recorded by means of a computerized data acquisition system.

The furnace gases are monitored at various locations for carbon monoxide and oxygen and continuously recorded. Stack

sampling for type and quantity of contained solids and gases is carried out intermittently.

The ambient air quality in the working area is monitored intermittently for total air volume and concentrations of particulates. Over the period for the total test run, the weighted average for the particulates was well within acceptable limits.

A thermodynamic model of the PEAR was developed to provide data on:

1 Energy required to heat up the furnace lining to a given temperature.
2 Energy lost through the furnace lining at given hot face temperatures.
3 Interface temperatures in the furnace lining at given hot face temperatures.
4 Energy required to heat up, melt and react a given quantity of composite furnace feed.
5 Heat content and heating value contained in the furnace gases at given furnace throughput and reaction temperatures.
6 Reducing agent required for given fixed carbon, ash and moisture in the reducing agent and given quantity and compositions of feed.
7 Type and quantity of fluxes required for a given aim slag composition.
8 Ratio EAFD to flux addition for a given furnace throughput
9 Material balance for a given composite furnace feed.

2.3.2 SUMMARY OF EQUIPMENT MODIFICATIONS

In the course of this project from the Fall of 1985 to February 1987 a number of equipment modifications were required to improve operations. These modifications are summarized as follows:

1. FEED SYSTEM. The star feeder was modified to reduce breakage of the briquets and increase feed rate.

2. ELECTRODE ASSEMBLY. Changes were made to the

electrical insulation and to the design and materials of construction to eliminate arcing and improve sealing.

3. FURNACE LINING. Changes were made to the back up refractories and the inner lining to avoid premature failures due to the start up and shut down modes of the operation. The hot face of the furnace needed to be totally lined with carbon to avoid melting of the oxide refractories due to plasma arc radiation.

4. FURNACE EXIT. The size of the pipes was enlarged to improve gas flow. Temperature levels were improved by installing graphite inner liners.

5. GAS SAMPLING. The system was improved to avoid blockage of the small-diameter tubes.

6. ZINC CONDENSER. Modifications were necessary to reduce emissions, prevent heat losses, expedite installation of gas burners, seal roof section, facilitate removal of molten zinc.

7. CROSS-OVER PIPES. Install purge lines to remove dust deposits.

8. CONTROL PANEL. Reduce the speed of the linear actuators to avoid electrode breakage. Improve manual input and visual output.

2.3.3 TEST RESULTS - MELTING IRON

During the period March to August 1986 initial tests were conducted to check out the furnace system and controls. Only cast iron was fed during this series, augmented by small quantities of mill scale and blast furnace slag during the latter part of the period. There were a number of shut downs and repairs to improve the hardware of the system.

The first three taps of metal were video taped; the first one by ORF, the second one by the Ministry of Energy and the third one by Howden Group Canada Limited.

Tables 1 to 3 show typical log book entries regarding these three taps. The metal produced showed typical cast iron structure under the microscope.

The temperature distribution in the furnace as recorded during the first melting campaign on March 7, 1986 is shown in Figure 3. It shows temperatures of eleven thermocouples from the beginning of the run to tapping of the furnace. Nos.1 to 5 thermocouples are located at the side of the furnace from top to bottom respectively. In most cases the tip of the couple is touching the cold face of the carbon brick inner lining. No.6 was placed right above the tap hole, Nos.7 to 10 in the top, and No.11 in the bottom lining. At that time there was no graphite lining installed in the roof and hearth sections of the furnace. The electrode assemblies were mounted to go through the roof in a near vertical direction.

It can be seen from Figure 4 that the sidewall refractory reached 1600'C after approximately four hours of operation. The roof section was lagging and reached only 1400'C or less in the same time period. The hearth couple followed similar trends as roof couples Nos.9 and 10.

Figure 5 shows the heating and cooling periods for the same run. The time is plotted in increments of 720 minutes or 12 hours.After 12 hours from start the refractory had cooled down to just under 800'C and after 24 hours to near 500'C. The cold face of the steel shell near No. 3 thermocouple had reached 162'C during the melting period and then cooled to 93'C.

Additional thermocouples were installed into the hearth section at various depth for the next run. The zinc condenser was built and commissioned during the latter part of this period.

2.3.4 TEST RESULTS - SMELTING IRON AND ZINC OXIDES

During the period September to October 1986 two runs were conducted employing millscale as the primary feed material augmented with zinc in the first test and zinc metal and zinc oxide in the second one. This was done to vapourize zinc and observe the

performance of the newly installed condenser without having the environmental constraints imposed by feeding EAFD into the furnace.

Tables 4 and 5 show the material balances for these runs. The results indicate that 111 lbs. of zinc or 84% were condensed in the first run, whereas 220 lbs. or 88% of the zinc values fed were calculated to be captured by the condenser. The balance of the zinc was recovered as dust from the cyclone and baghouse. Table 6 shows the log entries for the second run. It shows furnace operating times and reasons for stopping, type and quantity of feed as well as feed rates. Average power consumption is also shown. It can be noted that a total of 17 hrs and 28 min were required to produce 1,845 lbs of metal and slag at an average load of 0.39 MW. The specific power consumption was 2.09 KWH/lb feed. Feed rates during this run ranged up to 1.16 ton/hr.

2.3.5 TEST RESULTS - SMELTING ELECTRIC ARC FURNACE DUST

During the period November 1986 to February 1987 twelve runs were carried out employing electric arc furnace dust from Lake Ontario Steel Company, Whitby, Ontario. Typical compositions of this dust are shown in Table 7. Based on these analyses, zinc oxide ranges from 14 to 21%, lead oxide from 1.5 to 4%, cadmium oxide from .02 to.05%. The major constituents, next to zinc oxide, are iron oxide and lime.

The EAFD was briquetted at Metal Recovery Industries Inc., Burlington, Ontario employing a Komarek roll-type briquetting press. During the initial period straight dust was briquetted with molasses and lime as binder. For the second and third formulations a self-fluxing briquette was prepared containing controlled quantities of sand, alumina and magnesia. Table 8 shows the briquette formulation No.3 as used during the period January 26 to February 2, 1987.

The slag formulation that was aimed for had the following composition:

Weight%	Lime	34.00
	Magnesia	4.80
	Silica	51.70
	Alumina	9.50

The aim slag chosen has a low melting point (1300'C) at a molar ratio CaO/SiO2 of 0.80.

Table 9 shows the log entries of the fifth run on EAFD. A total of 1,125 lb of cast iron were fed to start, followed by 1,393 lb of millscale and coke and 1,776 lb of briquetted EAFD. Total power-on time was 21 hrs and 53 min. A total of 2,393 of iron was tapped along with 500 lb of slag. The load averaged 0.41 MW, yielding a specific power consumption of 2.04 KWH/lb feed. EAFD briquettes were fed at rates of up to 0.74 tons/hr whereas the average feed rate was 0.35 tons/hr.

A data acquisition summary is shown in Table 10 which describes part of the seventh run on EAFD which was conducted on January 27, 1987. During the feeding period of this run, power consumption in the reactor started to increase rapidly. Power input control was maintained between 0.6 and 0.9 MW. These large fluctuations of power input were the results of the change of the current arc characteristics during feeding. The power input control is very stable during the reactor heat-up and melt-down periods.

Reactor temperatures could be maintained at a constant level during the operation, suggesting that steady state conditions had been achieved. The reactor bath temperature, as measured by an optical pyrometer, ranged near 1500'C, which is a favourable temperature for tapping.

During a three hour period 1,860 lb briquettes were fed at a rate of 0.30 tons/hr consuming 1,550 KWH. Thus, specific power consumption during this period amounted to 0.83 KWH/lb briquettes.

Figure 6 depicts the reactor temperature profile and the reactor power. The thermocouple locations for the temperature profile are described in Table 10.

Table 11 shows log entries for the eleventh run on EAFD which was carried out from February 1 to 2, 1987. A total of 3,993 lbs. of briquettes were fed in a total of 7 hr 14 min 'power on' time. The maximum feed rate was 0.70 and the average rate was 0.31 tons/hr. The average specific power consumption amounted to 0.91 KWH/lb briquettes. Table 12 describes a 5 hr portion of this run in more detail with respect to temperatures of the system as well as gas flows and carbon monoxide/oxygen levels. During the initial period of feeding dust collection problems were experienced causing a slow down in processing. Power consumption at this period of time is low because of intermittent feed. Large fluctuations in currents and power input were observed. The slope of the rate of power consumption between this run and Pb7 during feeding is quite

similar and is calculated at 0.8 MWH/hr.

The temperature profile is graphed in Figure 7 along with a plot of KW and KWH during a 6 hr period of the run. The changes observed in the carbon monoxide and oxygen levels near the roof of the furnace are plotted in Figure 8. The carbon monoxide level was greater than 40%, whereas the oxygen was below 3%. The lower and upper explosion limits for carbon monoxide in air are 12.5 and 74.2% respectively.

Table 13 provides an overview for all of the runs with EAFD briquettes. A summary is given of all the feed additions made, the calculated weights of metal and slag, the tapped weight of metal and slag as well as a variance.

Table 14 gives a detailed material balance for individual metals and slag constituents in terms of quantities fed and recovered. It can be seen that 92% of the iron fed was recovered. Zinc and lead recovered in cyclone and baghouse dusts and drosses amounted to 66 and 32% respectively. Thus, 34% of the zinc and 68% of the lead fed were recovered into the condenser.Approximately twice the amount of alumina fed was recovered in the slag. The quantities for lime and silica are nearly balanced.

Table 15 lists the calculated briquette composition for the No.3 formulation which is based on the EAFD analysis.This composition is compared with those obtained on the individual barrel samples that were analyzed.Table 16 compares the aim slag composition with the average of actual slag analyses. Table 17 shows typical compositions of cyclone and baghouse dusts that were generated in the course of the last runs.

2.3.6 THEORETICAL CONSIDERATIONS

A thermodynamic model of the PEAR was developed taking into account the entropies of the feed and product constituents and their changes with temperature as well as heats of fusion and volatilizations where appropriate. The k values for the various refractories were used to compute interface temperatures and heat losses through the lining. The model was expanded to include material balances complementing the heat balance calculations.

Table 18 lists the calculated material balance for processing one ton of briquettes in terms of feed and product

constituents. The generation of large quantities of carbon monoxide is particularly noteworthy. According to Table 19 the heating value of the generated carbon monoxide amounts to 393 KWH or 1,342,000 BTU per ton of briquettes processed. Table 20 presents the calculated heat balance which is based on processing one ton of briquettes. It can be seen that the heat required to heat up the furnace refractory far exceeds the requirements to react a ton of briquettes. Approximately 4 MWH are needed to heat the empty furnace to the reaction temperature of 1500'C. For comparison, only 0.7 MWH will theoretically heat, melt and react a ton of briquettes. Table 21 suggests that the specific power consumption from cold start is 0.63 KWH/lb briquettes when processing 7 tons of briquettes without interruptions. The best actuals obtained were in the order of 0.80 KWH/lb briquettes.

2.3.7 ENVIRONMENTAL CONTROL

All work that concerned environmental control was conducted by the Environmental and Chemical Engineering Division of the Ontario Research Foundation. This included leachate testing, stack emission testing and air sampling surveys.

SLAG STABILITY

Ontario Regulation 309 leachate extraction tests were conducted on the feed briquettes as well as on the slags produced when feeding EAFD briquettes.

Regulation 309 refers to the revised regulations as amended to Ontario Regulation 464/85, under the Environmental Protection Act, November 1985.

According to these regulations, the leachate is toxic if the extract contains contaminants at concentrations equal to or greater than the following:

Cadmium	1.0 mg/L
Chromium	5.0 mg/L
Lead	5.0 mg/L

Zinc no limit

Figure 9 summarizes the results of the leachate tests indicating excellent stabilities of all slag samples for the toxic elements tested.

The cadmium levels in the slags ranged from less than 0.002 to 0.005 mg/L, the lead levels from less than 0.02 to 0.13 mg/L, the chromium levels from less than 0.01 to 0.01 mg/L.

EMISSION TESTS

Stack emission tests for total particulate material and metals were conducted on December 5, 1986, January 30, 1987 and February 1, 1987 during the plasma arc smelting of electric arc furnace dust.

Emission rates determined for each contaminant were used in dispersion equations to calculate maximum ground level impingement concentrations. These concentrations were compared with the maximum permitted concentrations given in the Ontario Environmental Protection Act Regulation 308 standards. The most environmentally significant contaminants were found to be particulate matter, metallic iron, lead, zinc and cadmium.

For the test conducted on December 5, 1986, emissions of particulate matter, lead, iron and zinc all exceeded current standards by 670%, 560%, 320% and 260% respectively. Cadmium emissions were found to be 22% of the standard. However, upon inspection of the baghouse after the experimental test run, approximately 20% of the bags were found to be damaged, probably by excessive temperatures. All bags in the baghouse were replaced before the next run.

During the next test run, stack tests were conducted on January 30 and February 1, 1987. Maximum impingement concentrations for all contaminants during these tests were well below current air pollution standards. Results from these tests, based on the calculated maximum permitted concentrations, were metallic iron (17%), total particulate (10%), lead (9%), zinc (4.6%), mercury (0.8%) and cadmium (0.4%).

AIR SAMPLING SURVEY

Occupational hygiene sampling surveys were carried out during the furnace operations. Personal and area air sampling was conducted for cadmium, lead, zinc and total dust. Sampling was carried out prior to processing, during periods of operation, and following conclusion of the runs.

The airborne contaminant levels were found to be well below their respective permissible occupational exposure limits with the exception of lead in a few samples. Airborne lead paralleled the processing of EAF dust. A number of samples showed lead concentrations which exceeded the permissible exposure limit.

In one case, the worker was heavily engaged in furnace charging as well as welding and other maintenance activities on the baghouse and the bucket elevator. In view of these activities, his high lead exposure is expected. It should be noted that that personal exposure concentrations if averaged over the period of this particular work week would likely not exceed the permissible time-weighted average exposure concentration of .015 mg/m3 as on some shifts the exposure to airborne lead was significantly lower.

In another case, two area samples were found to approach or exceed the permissible exposure limit. This likely occurred due to the disruption of the general ventilation pattern when the bay doors were opened for a longer period of time.

Table 22 summarizes the air sampling survey that was conducted during the period January 27 to February 3, 1987.

2.3.8 INTERACTION OF PEAR SYSTEM WITH LOCAL POWER SUPPLY

Ontario Hydro have been retained to monitor the interaction of the PEAR system with the local power supply.

On-site tests were conducted to monitor voltage and current waveforms, plus real and reactive power, under feed and no-feed conditions. Preliminary results indicate that flicker and harmonic content are within acceptable limits.

We are still awaiting the final report from Ontario Hydro and will supply more complete information as it becomes available to us.

2.4 DESCRIPTION OF INNOVATION

The Extended Arc Reactor is the significant part of the processing system. The innovation concerns the stabilization of the electric arc by injecting small but controlled quantities of argon through the centre of the graphite electrodes. As a result, the noise level diminishes and the secondary current that is discharged at the arc tips becomes more stable due to the formation of a plasma gas shroud. This plasma zone is much larger in volume than regular electric arc discharge.

The inherent advantages of a furnace operated in the plasma mode include:

1 Improved heat transfer due to larger arc zone.
2 More uniform heating of refractories,thus, less wear.
3 Lower electrode consumption when compared to standard electric arc furnaces since oxidation is eliminated.
4 Much less emissions around the furnace since it is totally enclosed.This feature makes it possible to process toxic materials such as electric arc furnace dust.

2.5 RESEARCH AND DEVELOPMENT REPORT

This project is still in the development stage and no final statements can be made as to process and equipment implementation. A number of changes have been made to the feed system, the electrode assemblies, the furnace lining, the gas exit pipes, the gas sampling system, the zinc condenser and the control panel and more changes are being planned.

It has been demonstrated, however, that the system is operational in an environmentally safe manner and the resulting products are environmentally stable.

Future efforts will concentrate on optimizing the operation in terms of higher feed rates at higher power input levels.

The operation of the condenser has not been satisfactory.

To-date, two thirds of the zinc and one third of the lead values were not recovered in the zinc condenser as metallics but rather were collected as dross or baghouse fines, primarily as oxides.

For maximum collection efficiencies the condenser needs to be run at zinc bath temperatures of at least 460'C to operate the stirrer which throws zinc droplets into the path of the furnace gas to capture the vapours of cadmium,lead and zinc. This stirrer,however, was run only for very short periods, thus, incomplete recovery of metallic lead and zinc resulted. To maintain the required zinc bath temperatures, a higher feed rate under power is required to generate more hot furnace gas which, in turn, provides more heat for the condenser.

2.6 MONITORING

All process and energy data have been discussed in section 2.3 Technical Description. Relevant data are appended.

2.7 COST/BENEFIT ANALYSIS

The PEAR System is a site specific operation processing EAFD at the steel plant site. Since there are variations in the dust composition and plant practices as well as in the cost of the current practice of transporting EAFD to landfill sites quite different cost/benefit scenarios will result. These scenarios need to be worked out for each specific plant which has not been done as yet.

2.8 Discussion

The major benefits that may be derived from the operation of such a system are environmentally clean and safe processing conditions of a waste material that will be increasingly costly to

dispose of in the future.

The major problems encountered at this stage of the development concern increased throughput at higher power levels and modifications to the condenser for improved collection efficiencies of lead and zinc.

2.9 CONCLUSIONS AND RECOMMENDATIONS

Processing of approximately eight tons of EAFD briquettes in the first production size Plasma Extended Arc Reactor at average feed rates of 0.3 to 0.5 tons/hr and average power inputs of 0.4 to 0.5 megawatts/hr yielded cast iron and an environmentally stable slag at good recoveries and grades. One third of the zinc and two thirds of the lead contained in the EAFD briquettes was recovered as metallics into the zinc splash condenser, the balance of these values were accounted for as oxides in drosses, cyclone and baghouse dust. These waste products are suitable for direct recycling into the PEAR as briquettes. The air quality near the PEAR system was within the Ontario regulation standards. The same was true for the stack emissions, once the defective bags were replaced with new ones for the balance of the test runs.

It is felt that the program to-date has been successful. Additional work is required to complete this phase of the project. A higher feed rate at increased power levels is one of the tasks to be undertaken, another one is the modification of the condenser to allow for greater recoveries of lead and zinc. These optimization efforts have to be completed before cost/benefit analyses can be performed for site specific cases.

owden PEAR R+D No.001

TABLE 1

RUN Fe 1 Log Entries

Date	07-Mar-86			
Run Number	8		Melt Charge	lbs
Power Reading Start (MWH)	8.9			
Power Input		Reason	Cast Iron Scrap	2000
Start	08:27		Metallurgical Coke	60
Stop	12:52	AECL interuption	Coke	50
Start	13:51			
Stop	14:30	Tapping		
Power Reading End (MWH)	12.02			
Power Consumption (MWH)	3.12			
Duration of Melt Test(HH:MM)	05:04			
Average Power (MWH)	0.616			

TABLE 2

RUN Fe 2 Log Entries

Date	25-Mar-86		
Run Number	9	Melt Charge	lbs
Mega Ohm Test	A:100 kohm, B:100 kohm, C:100 kohm		
		Cast Iron from previous mel	500
Power Input	Reason	Crushed electrodes -1in.	40
Start	05:23	Cast Iron Scrap -1/2in.	1320
Stop	11:01 Tapping	Crushed electrodes -1in.	61

Power Reading Start (MWH)	2.20
Power Reading End (MWH)	6.00
Power Consumption (MWH)	3.80
"Power On" time	10:26
Average Load/Hr.	0.750

COMMENTS

8:00 am Cut back power to approx. 2/3 to equilibrate temperatures top vs. bottom
8:58 am Lost #3 and #4 T/C. #3 hole has unobstructed view into furnace
9:36 am Gas composition in feed tube: Vol% CO = 2.0, Vol% O2 = 2.0
Ratio CO/O2 = 1.0 (LEL = .7)
9:37 am Fed approx. 60 lbs sized cast iron (-1/2 in. +35mesh)
for the first time into the hot furnace using the bucket elevator
10:52 am Red hot #2 electrode flange, red hot feed flange
11:00 am Lost control power to #3 electrode
11:01 am Power off
11:10 am Started to open tap hole
11:15 am Howden Board arrives
11:24 am Finished tapping

No CO gas during run, a good burn resulted when opening bottom of hot cyclone
A gas burn resulted when feeding cast iron through the feed system at a CO/O2 ratio = 1.0

TABLE 3

RUN Fe 3 Log Entries

Purpose: Melt iron and slag, then tap furnace

Date: April 3, 1986
Run Number 10

03-Apr-83	Start	05:22 Fed 2000 lb coarse cast iron cold
	Stop	07:28 Fed 18 lb crushed graphite
	Start	07:44 Fed 18 lb crushed graphite under power
		07:55 Feeding 500 lb cast iron
		09:07 Fed 500 lb C.I. in 5 min under power - o.k.
		09:29 Cut power to 1/3 MW
		09:43 Fed 500 lb cast iron in 5 min
		09:49 Fed 300 lb B/F slag
		11:14 Water leak #3 electrode
	Stop	11:15 Prepare for tapping

Time Power On	05:37 (HH:MM)
Power Reading Start (MWH)	6.00
Power Reading End (MWH)	10.10
Power Consumption (MWH)	4.10
Average Power (MWH)	0.730

TABLE 4

RUN ZINC1 MATERIAL BALANCE, SEPTEMBER 25, 1986

Test	Wt. in lb	Composition Wt.%		lb Metal fed or recovered		% Metal recovered		Balance to 100 %	
ZINC1		Fe	Zn	Fe	Zn	Fe	Zn	Fe	Zn
Feed:Millscale,Fe3O4	2,272	72.36	0.00	1,644	0	100	0.0	100.0	0.0
Coke,C	530	0.00	0.00			0.0	0.0	0.0	0.0
Zinc granules	250	0.00	100.00	0	250	0.0	100.0	0.0	822.7
OUT:Metal	898	96.00	0.00	862	0	52.4	0.0	98.6	0.1
Slag	0	1.00	0.00	0	0	0.0	0.0	0.0	0.0
Cyclone Dust est	15	36.80	10.20	6	2	0.3	0.6	0.6	5.0
Baghouse, estm'd	55	11.80	52.40	6	29	0.4	11.5	0.7	94.8
Total Recovered				874	30	53.2	12.2	100.0	100.0
Zinc Condensed					220		87.8		

Note: Metal weight as tapped. There was no slag.

TABLE 5

RUN ZINC2 MATERIAL BALANCE, OCTOBER 8 TO 10, 1986

Test	Wt. in lb	Composition Wt.%		lb Metal fed or recovered		% Metal recovered		Balance to 100 %	
ZINC2		Fe	Zn	Fe	Zn	Fe	Zn	Fe	Zn
Feed:Millscale,Fe304	1,676	72.4	0.0	1,213	0	100	0.0	0.0	0.0
Coke,C	477	0.0	0.0			0.0	0.0	0.0	0.0
Zinc granules	99	0.0	100.0	0	99	0.0	75.0	0.0	471.5
ZnO Prills	41	0.0	80.3	0	33	0.0	25.0	0.0	156.9
Blast F'ce Slag	500	1.0	0.0	5	0	0.4	25.0	0.4	156.9
OUT:Metal	1,345	92.7	0.0	1,247	0	102.8	0.0	99.4	0.1
Slag	500	1.0	0.0	5	0	0.4	0.0	0.4	0.0
Cyclone Dust	2	39.1	8.1	1	0	0.1	0.1	0.1	0.8
Baghouse, 1+2	13	2.5	49.7	0	6	0.0	4.9	0.0	30.8
Baghouse, 3+4	25	7.5	57.4	2	14	0.2	10.9	0.1	68.4
Total Recovered				1,255	21	103.5	15.9	100.0	100.0
Zinc Condensed					111		84.10		

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TABLE 6

RUN ZINC 2 Log Entries

rpose: Process iron oxide, zinc oxide and zinc to produce metal and slag.
Prepare a zinc balance.

te: October 8 to 10, 1986
Me Ohm TeA: 3.5 kohm, B: 5 kohm, C: 15 kohm

08 :t-86	Start	09:11	
	Stop	09:12	C/T Wires shorting
	Start	11:07	
	Stop	13:06	#1 and #3 EL need slipping
	Start	13:29	Changed to B tap
	Stop	13:40	Sticking of push buttons/EL
	Start	15:12	
	Stop	18:00	Power off for the day
09 :t-86	Start	09:02	
	Stop	09:24	Changed to C tap, install key switch
	Start	10:15	
	Stop	11:00	Off to soak
	Start	13:50	
	Stop	15:35	Change to D tap
	Start	15:50	
	Stop	17:09	Change to C tap
	Start	17:14	
	Stop	17:45	Change to B tap, slip #3 EL 3 in.
	Start	18:05	
	Stop	18:42	Change to C tap
	Start	18:55	
	Stop	19:15	Power off to tap slag
	Start	20:00	
	Stop	21:20	Try to tap some more
	Start	22:45	
	Stop	23:40	Try tap again
10 t-86	Start	07:00	Start on "C" tap
	Stop	09:00	no arc
	Start	11:05	
	Stop	13:40	Power off to tap
	Stop	14:00	Tap finished

Time Power On 17:28 (HH:MM)

Melt Charge	Lbs	Start HH:MM	Finish HH:MM	Time HH:MM	Individ Feed Rate Tons/Hr	Bulk Feed Rate Tons/Hr
Millscale	508	02:03	02:34	00:31	0.49	
Coke	142	02:03	02:34	00:31	0.14	0.63
Millscale	499	02:50	03:17	00:27	0.55	
Coke	140	02:50	03:17	00:27	0.16	
Zinc	106	02:50	03:17	00:27	0.12	0.83
Millscale	465	03:17	03:35	00:18	0.78	
Coke	130	03:17	03:35	00:18	0.22	
Zinc	99	03:17	03:35	00:18	0.17	1.16
B/F Slag	500	03:17	04:07	00:50	0.30	0.30
Millscale	204	04:21	04:45	00:24	0.26	
Coke	65	04:21	04:45	00:24	0.08	
Zinc Oxide	41	04:21	04:45	00:24	0.05	0.39
Silica Sand	10	01:10	01:12	00:02	0.15	

Power Reading Start (KWH)	0
Power Reading End (KWH)	6076
Power Consumption (MWH)	6.076
Power On* Time (HH:MM)	17:28
Average Load (MW)	0.393
Specific Power Consumption (KWH/lb feed)	2.089

Product Weight	Lb
Metal	1,345
Slag	500

TABLE 7

TYPICAL COMPOSITIONS OF EAF DUSTS

WEIGHT %	PLANT A	PLANT B
CARBON	1.67	---
Fe_3O_4	33.14	36.38
ZnO	20.70	13.78
PbO	3.63	1.37
CdO	0.046	0.021
MnO	2.98	3.76
Cr_2O_3	0.31	0.47
Na_2O	1.55	0.65
K_2O	1.46	1.38
Chlorine	2.12	---
Sulphur	0.24	0.17
P_2O_5	0.45	0.26
CaO	15.65	25.41
MgO	2.20	2.24
SiO_2	3.09	2.48
Al_2O_3	0.83	0.65
Mercury (PPM)	---	0.60
TOTAL	90.07	89.62

TABLE 8

BRIQUETTE FORMULATION RUNS Pb6 TO Pb12

JANUARY 26 TO FEBRUARY 2, 1987

	Kg	Weigh Batch
EAF Dust	586.6	404
Wet coke	89.4	64
Lime	0.0	0
Magnesia	4.8	3
Silica	168.1	120
Alumina	25.7	18
Molasses	91.8	67
Free Lime	33.8	25
Free Water	43.5	32
TOTAL	1043.7	733 lb wet weight

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TABLE 9

RUN Pb 5 Log Entries

rpose: Process EAFD Briquets (MRI#2), tap metal and slag and collect zinc

te: December 2 to December 5, 1987

Continuation from Run Pb 4

2-Dec-86	Start	19:05		Start	09:15
	Stop	19:23 Lower E holder stops		Stop	09:48 To soak
	Start	19:53 Feed Cast Iron 500 lb		Start	11:32
	Stop	20:16 To soak		Stop	12:00 To soak
	Start	21:16 Feed Cast Iron 500 lb		Start	13:30
	Stop	22:02 To soak, empty collectors		Stop	13:55 Unplug cyclone
	Start	22:34		Start	14:44 Feed M/S+C
	Stop	22:51 To soak, empty collectors		Stop	14:56 Plugged feed line
	Start	23:54		Start	16:30 "D" tap
3-Dec-86	Stop	00:18 To soak, empty collectors		Stop	16:42 Clear hard disc
	Start	01:27		Start	17:01 Continue feeding
	Stop	02:00 To soak, empty collectors		Stop	18:20
	Start	02:53		Start	18:27 Changed to MRI#3
	Stop	03:21 To soak, empty collectors		Stop	18:56 To soak
	Start	04:25		Start	20:04
	Stop	04:45 To soak, empty collectors		Stop	21:06 To soak
	Start	06:35		Start	22:00
	Stop	07:05 Removed E blocks for repair		Stop	22:30 To soak,lowered E stops
	Start	21:30		Start	23:43
	Stop	22:47 To check temperatures	05-Dec-86	Stop	00:00 To soak
	Start	23:18		Start	01:10
	Stop	23:40 Lower E stops		Stop	01:36 To soak
	Start	23:46		Start	02:42
4-Dec-86	Stop	00:21 To soak		Stop	03:04 To soak
	Start	01:01		Start	04:15
	Stop	01:18 To soak		Stop	04:42 Slip electrodes
	Start	02:09		Start	06:25
	Stop	02:30 To soak		Stop	07:22 To soak
	Start	03:15		Start	09:24
	Stop	03:38 To soak		Stop	09:33 Sight port leaking
	Start	04:30		Start	09:38 Feeding M/S+C+briquets
	Stop	04:47 To soak		Stop	11:36 Lower E stop
	Start	05:47		Start	11:46 Feeding briquets
	Stop	06:05 To soak		Stop	12:26 Lower E stop
	Start	07:11		Start	12:31 Stop feed to help bath temp
	Stop	07:35 To soak		Stop	12:52 Bath temp 1600° C

Sum "Power On" Time
10:47

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TABLE 9 continued

RUN Pb 5

			Melt Charge	Lbs	Star HH:M	Finish HH:MM	Time HH:MM	Feed Rate Ton \Hr
05-Dec-86	Start 12:57	Continue feeding briquets	Cast iron	500	19:56	20:16	00:20	0.75
	Stop 13:18	Pyro reading	Cast iron	625	21:16	21:47	00:31	0.60
	Start 13:20		Millscale+coke	1266	14:44	18:12	03:28	0.18
	Stop 13:30	Lower E stops	Millscale+coke	127	09:58	10:06	00:08	0.48
	Start 13:32	0.7 MW	Briquettes	60	10:46	10:55	00:09	0.20
	Stop 14:04	Pyro 1488' C	Briquettes	420	10:55	11:22	00:27	0.47
	Start 14:08		Briquettes	35	11:22	11:32	00:10	0.10
	Stop 14:10	Change to "C" tap	Briquettes	466	11:46	12:15	00:29	0.48
	Start 14:16		Briquettes	595	12:57	13:23	00:24	0.74
	Stop 14:41	To soak	Briquettes	280	14:16	14:29	00:13	0.65
	Start 15:10							
	Stop 15:48	Ready for tapping	Total Feed	4,374		Total Tim	06:19	(HH:MM)
	Stop 16:50	Tapping in progress				Avg. Rate	0.35	Ton/Hr
	Stop 17:35	Tap complete				Max. Rate	0.75	Ton/Hr

Sum "Power On" Time
11:06

Power Reading Start (KWH)	13962
Power Reading End (KWH)	22867
Power Consumption (MWH)	8.905
"Power on" Time	21:53
Average Load (MW)	0.407
Specific Power Consumption (KWH/lb Feed)	2.036

Product Weight	Lb
Metal	2,393
Slag	500

DATA ACQUISITION SUMMARY -- EAFD TEST #7

[illegible]ate : Jan 27, 1987
[illegible]eactor conditions before feed : 260 lbs. Mill scale + Coke fed in
670 lbs. of EAFD formula 2 briquette fed in

Reactor top	#9 T/C	-- 1340 deg. C
Reactor side	#7 T/C	-- 1420 deg. C
Reactor bottom	#6 T/C	-- 1160 deg. C
Reactor exhaust	#15 T/C	-- 900 deg. C
Electrode area	#12 T/C	-- 1180 deg. C

[illegible]tart feed time : 3 hr. (22:20 pm)
[illegible]nd feed time : 6 hr. (01:30 am)
[illegible]eed duration : 3 hrs.
[illegible]otal feed : 1860 lbs.
[illegible]eed rate : 0.3 ton/hr

[illegible]otal power consumed : 1550 kWH
[illegible]oltage tap setting : C, B

[illegible]ax. reactor temp. : 1420 deg. C (#7 T/C)
[illegible]ath temp. : 1475 deg. C (optical pyrometer)

[illegible]inc Condenser max. inlet temp. : 859 deg. C

[illegible]in control speed : 60 Hz

[illegible] gas flow : 7 l/min
[illegible]2 gas flow : 7 l/min

[illegible]raphs : 1) Reactor Temp. Profile
2) Reactor Power

[illegible]rocess Comments: No significant operating problems.
The system had been operated quite efficiently over the whole period. Temperatures around the reactor were under control. No overheating was observed. The feed system may be the limiting factor, resulting in lack of reaction gas volume to drive the zinc condenser. Zinc condenser splasher was turned on and off intermittently. Dust collection/cleaning were carried out periodically.

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TABLE 11

RUN Pb 11 Log Entries

urpose: Process EAFD Briquettes (MRI#3), tap metal and slag and collect zinc

ate: February 1, 1987

Continuation from Run Pb 10

01-Feb-87 Start 12:32 Heat to feed
Stop 13:20 Lower E holder stops
Start 13:24 Continue feeding
Stop 14:20 Check bath temperature
Start 14:21 Changed to B tap
Stop 14:52 Empty cyclone, baghouse, slip 3 E
Start 16:50 Heat to feed
Stop 18:20 Empty exhaust, baghouse
Start 19:00
Stop 19:20 Move E stops
Start 19:43 Continue feeding
Stop 19:46 Repair seal cyclone
Start 21:44 Continue feeding
Stop 23:44 Repair rear sight glass
02-Feb-87 Start 00:07 Continue feeding
Stop 01:13 Ready for tapping

Time Power On 07:14 (HH:MM)

Melt Charge	Lbs	Start HH:MM	Finish HH:MM	Time HH:MM	Feed Rate Ton \Hr
Briquettes	100	12:55	13:04	00:09	0.33
Briquettes	625	13:06	14:13	01:03	0.30
Briquettes	641	14:22	17:20	01:00	0.32
Briquettes	632	17:20	19:28	01:28	0.22
Briquettes	642	19:28	20:40	01:12	0.27
Briquettes	681	20:40	23:45	01:07	0.30
Briquettes	672	23:55	00:24	00:29	0.70
Total Feed	3,993		Total Time	06:28	(HH:MM)
			Avg. Rate	0.31	Ton/Hr
			Max. Rate	0.70	Ton/Hr

Power Reading Start (KWH)	10540
Power Reading End (KWH)	14177
Power Consumption (MWH)	3.637
"Power on" Time	07:14
Average Load (MW)	0.502
Specific Power Consumption (KWH/lb Briquettes)	0.311

Product Weight	Lb
Metal	130
Slag	1454

DATA ACQUISITION SUMMARY -- EAFD TEST #11

[illegible]ate : Feb 1, 1987
eactor conditions before feed : One ton of EAFD formula 2 briquette fed in

Reactor top	#9 T/C	-- 1250 deg. C
Reactor side	#7 T/C	-- 1330 deg. C
Reactor bottom	#6 T/C	-- 1050 deg. C
Reactor exhaust	#15 T/C	-- 1000 deg. C
Electrode area	#12 T/C	-- 1060 deg. C
Carbon Monoxide	Vol %	-- 42 %
Oxygen	Vol %	-- 2 %

[illegible]tart feed time : 0 hr. (19:28 pm)
nd feed time : 5 hr. (00:24 am)
eactor Tap time : 6 hr. (01:13 am)
[illegible]eed duration : 5 hrs.
[illegible]otal feed : 1975 lbs.
eed rate : 0.2 ton/hr

[illegible]otal power consumed : 1575 kWH
oltage tap setting : C

[illegible]ax. reactor temp. : 1450 deg. C (#7 T/C)
ath tap temp. : 1493 deg. C (optical pyrometer)
lag tap temp. : 1215 deg. C (optical pyrometer)

inc Condenser max. inlet temp. : 809 deg. C

an control speed : 38 Hz

ax. CO conc. : 47 %
ax. O2 conc. : 3 %

r gas flow : 7 l/min
2 gas flow : 7 l/min

raphs : 1) Reactor Temp. Profile
2) Reactor Power
3) Reactor Top CO, O2 Conc.

rocess Comments: Because of dust collection problems, the system had not been operated efficiently during the first 2 1/2 hours.

TABLE 13

MATERIAL BALANCE - Pb1 TO Pb12 RUNS

NOVEMBER 20, 1986 TO FEBRUARY 2, 1987

Date	Tap No.	Feed Additions: Mill Scale	Coke	Cast Iron	Briquettes	Bauxite+ Silica	Calculated Weight: Metal	Slag	Zinc+ Lead	Tapped Weight: Metal	Slag	Zinc+ Lead	Iron and Slag Variance: Left in F'ce	Cumulative in F'ce
Nov-86	Tap Pb1	1,779	449	0	750	289	1,519	446	0	2,210	250	0	(495)	(495)
Nov-86	Tap Pb2	2,389	631	0	575	222	1,056	342	0	525	28	0	845	350
Nov-86	Tap Pb3	5,891	1,802	700	0	0	2,833	0	0	600	235	0	1,998	2,348
Dec-86	Tap Pb4	1,582	418	700	0	0	1,093	17	0	400	275	0	435	2,783
Dec-86	Tap Pb5	1,300	346	0	1,576	0	1,166	622	0	2,393	500	0	(1,105)	1,678
Jan-87	Tap Pb6	0	0	1,700	0	0	1,700	0	0	1,655	0	0	45	1,723
Jan-87	Tap Pb7	320	60	0	3,843	0	911	1,466	467	868	2,535	0	(1,026)	697
Jan-87	Tap Pb8	200	60	0	1,907	0	484	727	231	0	790	0	421	1,118
Jan-87	Tap Pb9	200	60	0	2,543	0	594	970	309	200	1,094	0	270	1,388
Feb-87	Tap Pb10	0	0	0	1,317	0	228	502	160	0	372	0	358	1,746
Feb-87	Tap Pb11	100	30	0	3,943	0	759	1,504	479	130	1,454	205	679	2,425
Feb-87	Tap Pb12	0	0	0	0	0	0	0	0	604	831	0	(1,435)	990
	TOTAL	13,761	3,856	3,100	16,454	511	12,343	6,596	1,646	9,585	8,364	205	990	

TABLE 14

MATERIAL BALANCE - Pb6 TO Pb12 RUNS

JANUARY 26 TO FEBRUARY 2, 1987

Runs	ACTUAL WEIGHTS	COMPOSITION Wt.%						CONTAINED VALUES LBS.					
Pb6 - Pb12	Lbs.	Fe	Zn	Pb	Al2O3	SiO2	CaO	Fe	Zn	Pb	Al2O3	SiO2	CaO
IN: Millscale	820	72.36	0.00	0.000	0.00	0.00	0.00	593	0	0	0	0	0
Cast iron	1,700	96.00	0.00	0.000	0.00	0.00	0.00	1632	0	0	0	0	0
MRI#3 briquet	13,553	13.47	9.34	1.894	3.16	18.36	12.07	1826	1266	257	428	2488	1636
TOTAL IN	16,073							4,051	1,266	257	428	2,488	1,636
OUT: Iron 6-12	3,457	96.00	0.00	0.000	0.00	0.00	0.00	3319	0	0	0	0	0
Slag 7	2,535	2.28	0.23	0.120	11.18	34.55	19.00	58	6	3	283	876	482
Slag 8	790	7.15	0.10	0.020	13.55	35.96	23.18	56	1	0	107	284	183
Slag 9	1,094	11.70	0.11	0.020	8.83	37.25	19.88	128	1	0	97	408	217
Slag 10	372	1.44	0.03	0.030	17.09	33.71	30.73	5	0	0	64	125	114
Slag 11	1,454	9.74	0.90	0.030	9.47	40.14	21.52	142	13	0	138	584	313
Slag 12	831	0.47	0.25	0.010	16.59	40.15	23.88	4	2	0	138	334	198
Cyclone 6	51	7.33	8.16	2.200	2.41	4.43	2.00	4	4	1	1	2	1
Cyclone 7	24	9.25	21.03	10.450	3.83	10.40	4.51	2	5	3	1	2	1
Cyclone 9	40	6.99	40.17	13.930	4.00	12.00	3.46	3	16	6	2	5	1
Cyclone 11	10	6.05	36.02	10.370	5.14	13.10	3.46	1	4	1	1	1	0
Cyclone 12	4	7.18	49.07	24.100	2.16	4.66	2.64	0	2	1	0	0	0
Baghouse 6	88	2.92	37.47	8.880	2.16	5.51	2.58	3	33	8	2	5	2
Baghouse 7	4	3.18	63.43	10.820	2.20	7.65	2.80	0	3	0	0	0	0
Baghouse 8	80	2.48	64.80	7.910	2.30	6.00	2.89	2	52	6	2	5	2
Baghouse 10	124	2.31	66.68	9.650	1.29	3.20	1.40	3	83	12	2	4	2
Baghouse 11	57	1.97	69.95	9.590	0.83	2.54	0.91	1	40	5	0	1	1
Baghouse 12	142	1.82	65.50	9.480	0.58	3.44	0.87	3	93	13	1	5	1
Dross 8	220	0.47	60.25	0.340	4.63	3.94	2.70	1	133	1	10	9	6
Dross 10	286	0.52	67.76	3.320	1.17	0.82	0.43	1	194	9	3	2	1
Dross 12	245	0.77	62.13	4.620	0.19	1.16	0.27	2	152	11	0	3	1
TOTAL OUT	11,908							3,737	835	82	851	2,655	1,528
ZINC and LEAD CONDENSED									431	174			

TABLE 15

COMPOSITION OF BRIQUETTES (MRI#3)
AVERAGE ACTUAL VERSUS CALCULATED

WEIGHT %	CALCULATED BASED ON EAFD ANALYSIS	AVERAGE ACTUAL BRIQUETTE ANALYSES OF FEED BARRELS
Carbon in Coke	7.11	13.48 (Total C)
Carbon in Molasses	3.67	---
Carbon in EAFD	0.98	---
Fe_3O_4	18.62	---
ZnO	11.63	13.56
PbO	2.04	2.35
CdO	0.026	0.016
MnO	1.68	n.d.
Cr_2O_3	0.12	n.d.
Na_2O	0.87	n.d.
K_2O	0.82	n.d.
Chlorine	1.19	n.d.
Sulphur	0.13	0.23
P_2O_5	0.25	0.24
CaO	12.07	11.43
MgO	1.71	1.89
SiO_2	18.36	16.07
Al_2O_3	3.16	3.04
Water for briquetting	4.50	5.00
Water from Molasses	5 70	5.70
Closure of EAFD analysis	5.83	---
TOTAL	100.47	73.01

TABLE 16

COMPARISON OF AIM SLAG COMPOSITION WITH AVERAGE ACTUALS - RUNS Pb6 TO Pb12

WEIGHT %	AIM SLAG	AVG. ACTUAL
CaO	34.00	28.00
MgO	4.80	11.65
SiO2	51.70	44.57
Al2O3	9.50	15.78
	100.00	100.00

TABLE 17

TYPICAL COMPOSITION OF CYCLONE
AND BAGHOUSE DUSTS

WEIGHT %	CYCLONE	BAGHOUSE
CARBON	10.33	2.92
Fe2O3	8.65	2.82
ZnO	44.84	87.07
PbO	11.17	10.33
CdO	0.001	0.043
Sulphur	1.53	0.03
P2O5	0.55	0.49
CaO	3.46	0.91
MgO	7.56	1.22
SiO2	13.10	2.84
Al2O3	5.14	0.83
TOTAL	106.33	109.50

TABLE 18

CALCULATED MATERIAL BALANCE
FOR PROCESSING 1 TON OF BRIQUETTES (MRI #3)

IN	Kg	%
EAF Dust	587	67.09
Flux	199	22.74
Carbon	74	8.46
coal Ash	4	0.46
Coal Moisture	10	1.14
Nitrogen	0	0.00
Argon	1	0.11
	875	100.00

OUT	Kg	%
Iron	141	16.18
Manganese	14	1.56
Chromium	1	0.10
Slag	369	42.14
Zinc	98	11.15
Cadmium	0.024	0.00
Lead	20	2.26
Carbide Carbon	11	1.28
Excess Carbon	0	0.00
Carbon Monoxide	148	16.88
Hydrogen	2	0.20
Nitrogen	0	0.05
Argon	1	0.09
Others	71	8.11
	875	100.00

wden PEAR R+D No.001

TABLE 19

CALCULATED GAS FLOWS EXITING PEAR
AND CONTAINED HEATS
FOR PROCESSING 1 TON OF BRIQUETTES (MRI #3)

	FLOWS SCF/Hr	L/Min	Kg/Hr	Mols	Heat Content KWH
N trogen	12	5.66	0.42	15	0.2
A gon	15	7.08	0.76	19	0.2
C rbon Monoxide	4,171	1,969	148	5,274	70.9
" drogen	692	327	1.75	875	11.0

	Gross Heating Value BTU	KWH
C rbon Monoxide	1,342,000	393
H drogen	225,000	66

TABLE 20

CALCULATED HEAT BALANCE
FOR PROCESSING 1 TON OF BRIQUETTES (MRI #3)
AT A TEMPERATURE OF 1500 'C

HEAT IN	KWH	HEAT OUT	KWH
Refractories	4,032	Refractories	57
Reducible Oxides and Coke	198	Metal/Slag	297
Reaction of Coke with Oxides	280	Zinc/Lead	67
Gangue Constituents	235	Gases	82
TOTAL HEAT IN	4,744	TOTAL HEAT OUT	503
		Heat retained in refractory	3975
		Heat of reaction	280
BALANCE	4,744		4,758

Howden PEAR R+D N0.001

TABLE 21

CALCULATED SPECIFIC POWER CONSUMTIONS
FOR PROCESSING 7 TONS OF BRIQUETTES
COLD FURNACE

KWH/lb BRIQUETTES	0.63
KWH/lb IRON	3.65
KWH/lb SLAG	1.66
KWH/lb Fe+Zn+Pb+SLAG	0.93

ACTUAL SPECIFIC POWER CONSUMPTIONS
HOT FURNACE

RUN Pb 7	KWH/lb BRIQUETTES	0.83
RUN Pb 11	KWH/lb BRIQUETTES	0.80

Howden Pear Project

TABLE 22

Howden Pear Air Sampling Survey Results
Ontario Research Foundation Pilot Plant 1
January 27 - February 3, 1987

Date	Shift	Employee/Location	Sample Volume	Airborne Total	Contaminant Concentrations Cadmium	Lead	Zinc
Jan. 27	PM	M. Petrovcic	848.06	-	0.0007	0.044	0.264
		F. Tam	877.76	-	N.D.	N.D.	0.002
		A. Staruszkiewicz	840.09	-	0.0011	0.046	0.029
		E. Recon	827.11	-	0.0012	0.039	0.208
		G. Adams	906.19	-	N.D.	0.035	0.248
		at baghouse	836.00	-	0.0012	0.147	0.884
		2nd floor landing, by offices	838.80	-	0.0012	0.246	1.753
		at Howden project gate	794.01	-	N.D.	0.030	0.198
Jan. 29	AM	1st floor, near east stairs	786.30	0.296	-	N.D.	0.003
		2and floor landing by offices	942.75	0.713	-	0.038	0.088
		at baghouse	865.35	0.908	-	0.043	0.127
		at Howden project gate	895.55	0.682	-	0.013	0.044
Jan. 29	PM	E. Recon	858.55	0.893	-	0.007	0.054
		E. Faber	841.68	0.880	-	0.004	0.031
		A. Staruszkiewicz	874.79	0.808	-	0.011	0.066
		G. Adams	878.94	1.083	-	0.018	0.088
		F. Tam	797.85*	0.073*	-	0.002*	N.D.
		at baghouse	1003.23	0.441	-	0.009	0.051
		2nd floor landing, by offices	957.16	0.190	-	0.002	0.007
		at Howden project gate	981.37	0.468	-	0.005	0.042
Jan. 30	AM	at baghouse	694.19	1.184	-	0.014	0.016
		2nd floor landing, by offices	687.76	0.788	-	0.007	0.019
		at Howden project gate	701.69	0.807	-	0.008	0.021

TABLE 22 Cont'd

Howden Pear Air Sampling Survey Results
Ontario Research Foundation Pilot Plant 1
January 27 - February 3, 1987

Date	Shift	Employee/Location	Sample Volume	Airborne Total	Contaminant Concentrations Cadmium	Lead	Zinc
Jan. 31	AM	H. Brandstatter	970.99	4.297	-	0.068	0.433
		F. Wiegers	886.16	-	-	0.237	1.354
		C. Jones	913.53	2.476	-	0.109	0.646
		P. Meredith	885.31	1.901	-	0.136	0.644
		P. Somerville	857.22	2.837	-	0.098	0.583
		at baghouse	914.30	2.419	-	0.153	1.028
		2nd floor landing, by offices	941.30	2.156	-	0.159	1.062
		at Howden project gate	962.81	1.167	-	0.065	0.395
		at control panel, by furnace	941.82	1.612	-	0.091	0.584
Feb. 3	AM	at baghouse	924.15	0.268	-	0.008	0.026
		2nd floor landing, by offices	929.73	0.348	-	0.005	0.017
		at control panel, by furnace	919.17	0.545	-	0.012	0.071

* concentration likely underestimated due to pump failure

Notes:

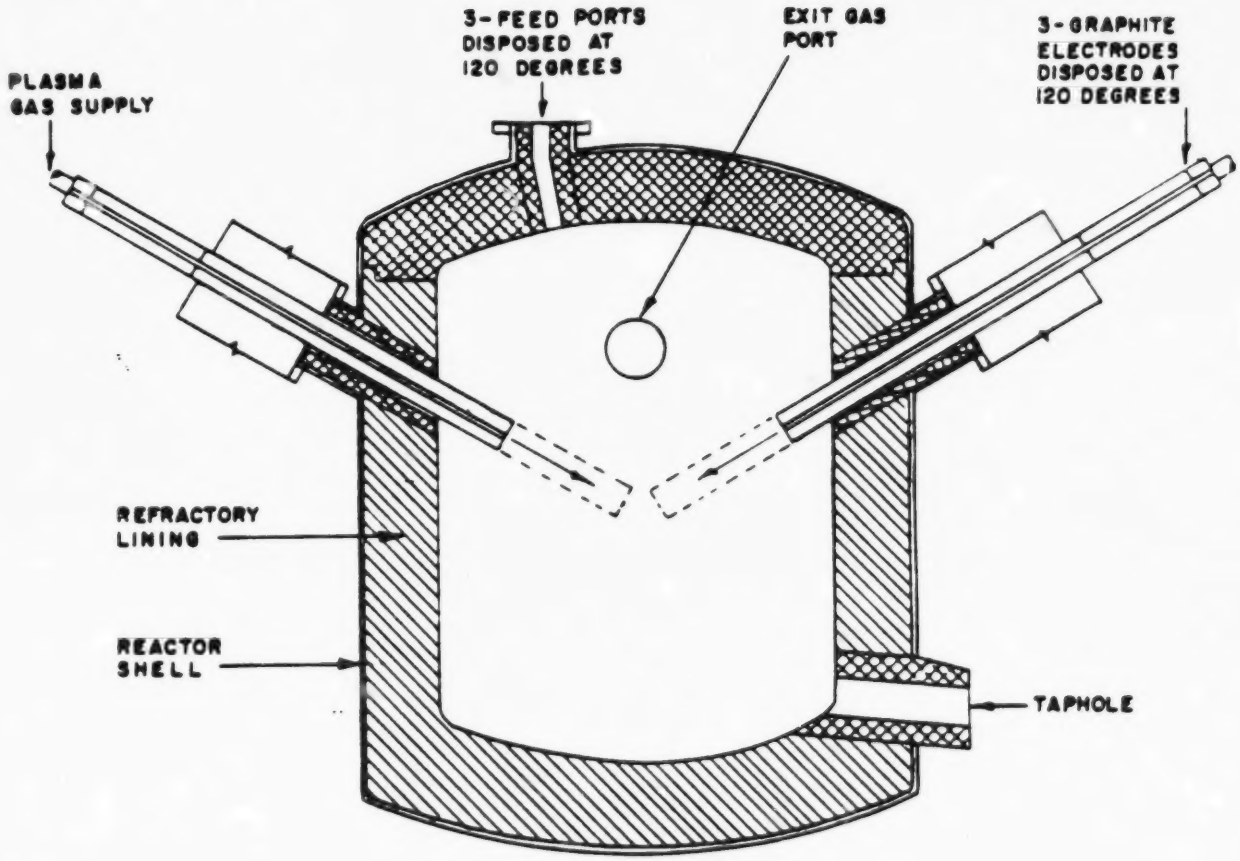
Jan. 29 - PM - process down
Jan. 30 - AM - process down
Jan. 31 - AM - process accelerated
Feb. 3 - AM - sampling following process shutdown

Permissible Occupational Exposure limits:

Total dust: 10 mg/m^3
Cadmium: 0.05 mg/m^3
Lead: 0.15 mg/m^3
Zinc: 5 mg/m^3

THE TIBUR HOWDEN PEAR SYSTEM

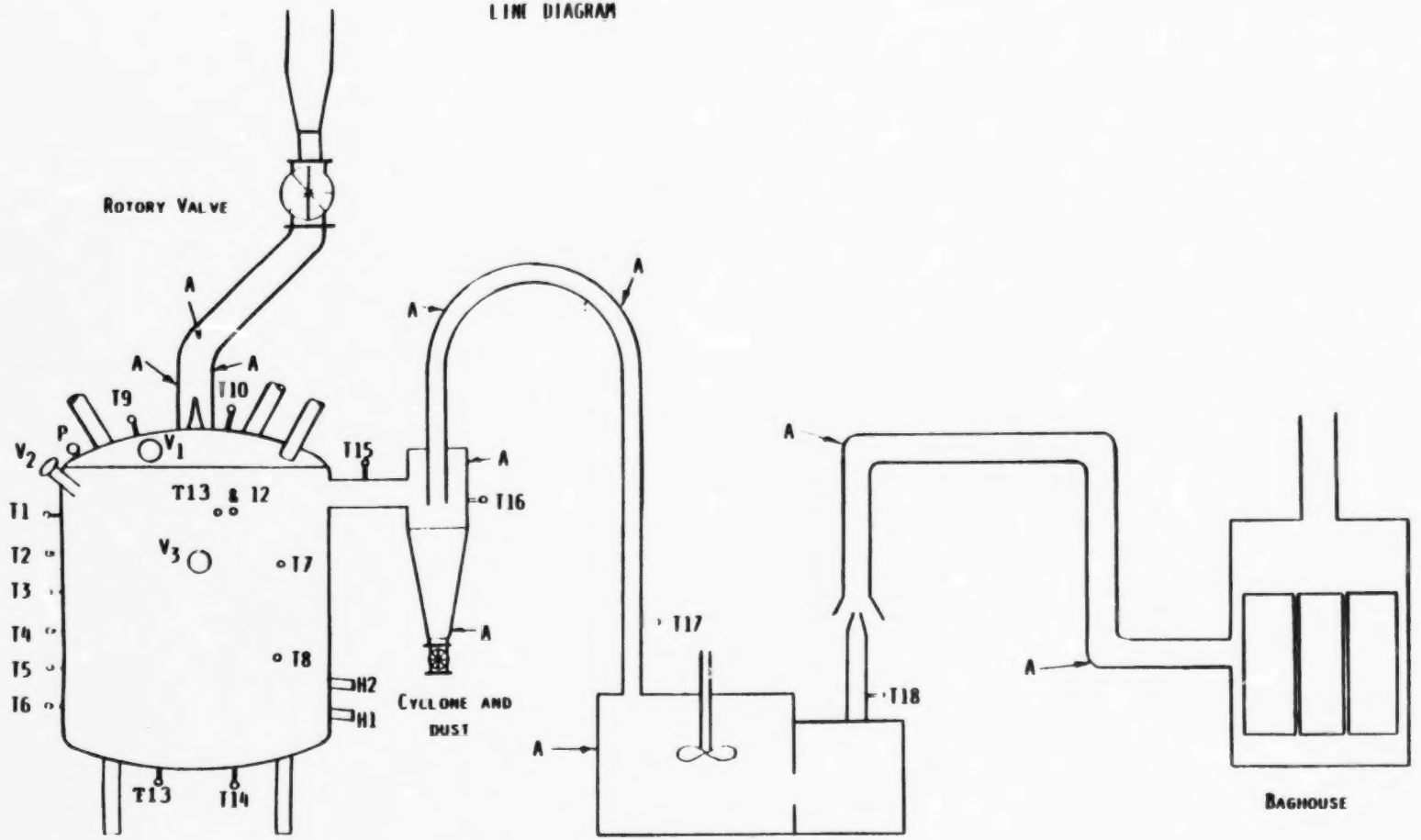
FIGURE 1



PLASMA EXTENDED ARC REACTOR

FIGURE 2

LINE DIAGRAM



REACTOR AND FEED MECHANISM

ZN /PB CONDENSER AND GAS BURN-OFF

A = ACCESS PORTS

H1, H2 = TAPHOLES

T_n O= = THERMOCOUPLES

P = PYROMETER WINDOW

V_1, V_2, V_3 = VIEWPORTS

FIGURE 3

PROCESS FLOW DIAGRAM

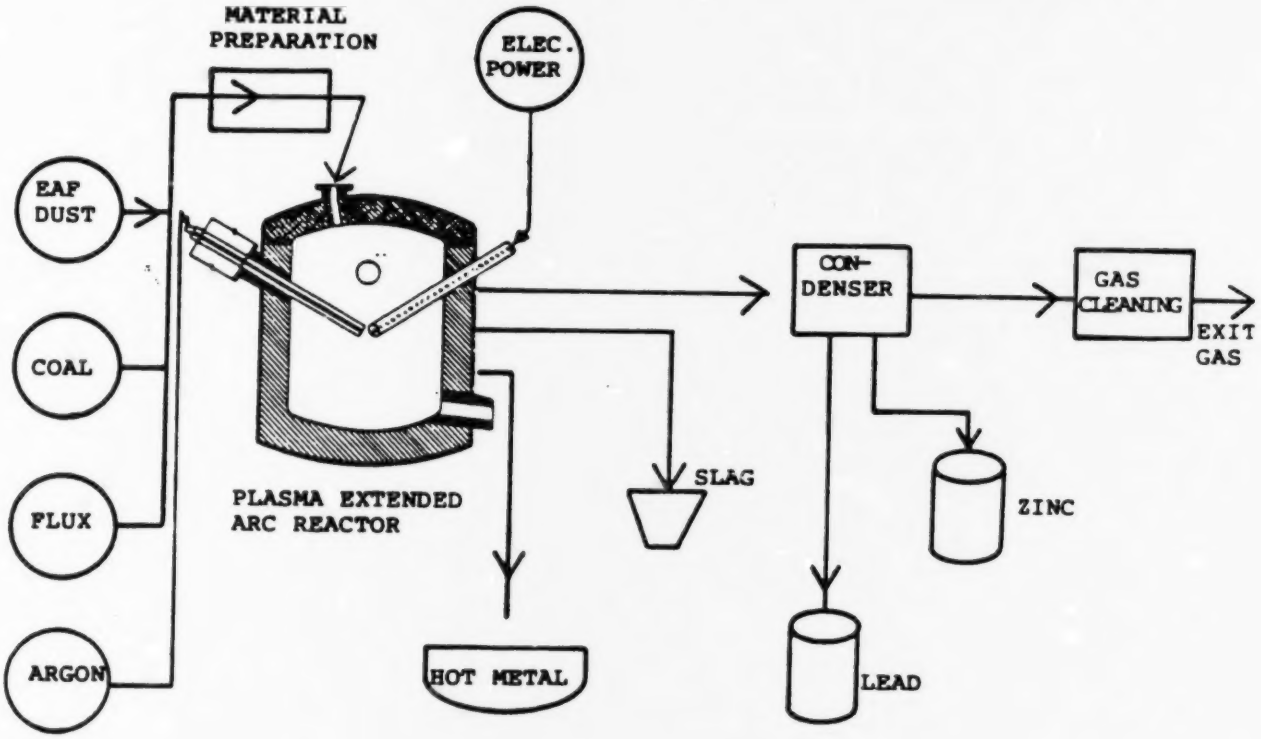


FIGURE 4

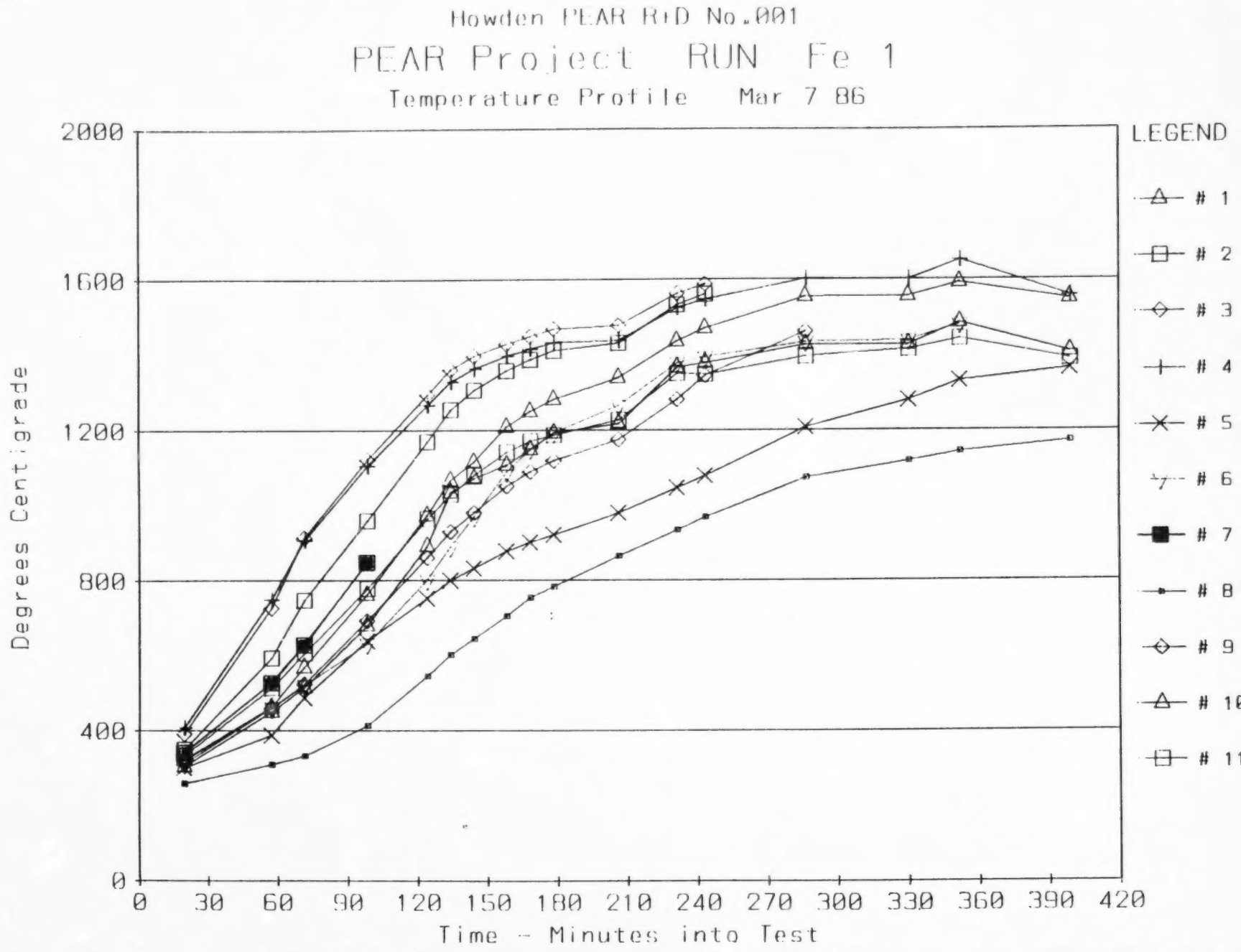

Howden PEAR RtD No.001
PEAR Project RUN Fe 1
Temperature Profile Mar 7 86
Degrees Centigrade
2000
1600
1200
800
400
0
0 30 60 90 120 150 180 210 240 270 300 330 360 390 420
Time - Minutes into Test
LEGEND
1
2
3
4
5
6
7
8
9
10
11

FIGURE 5

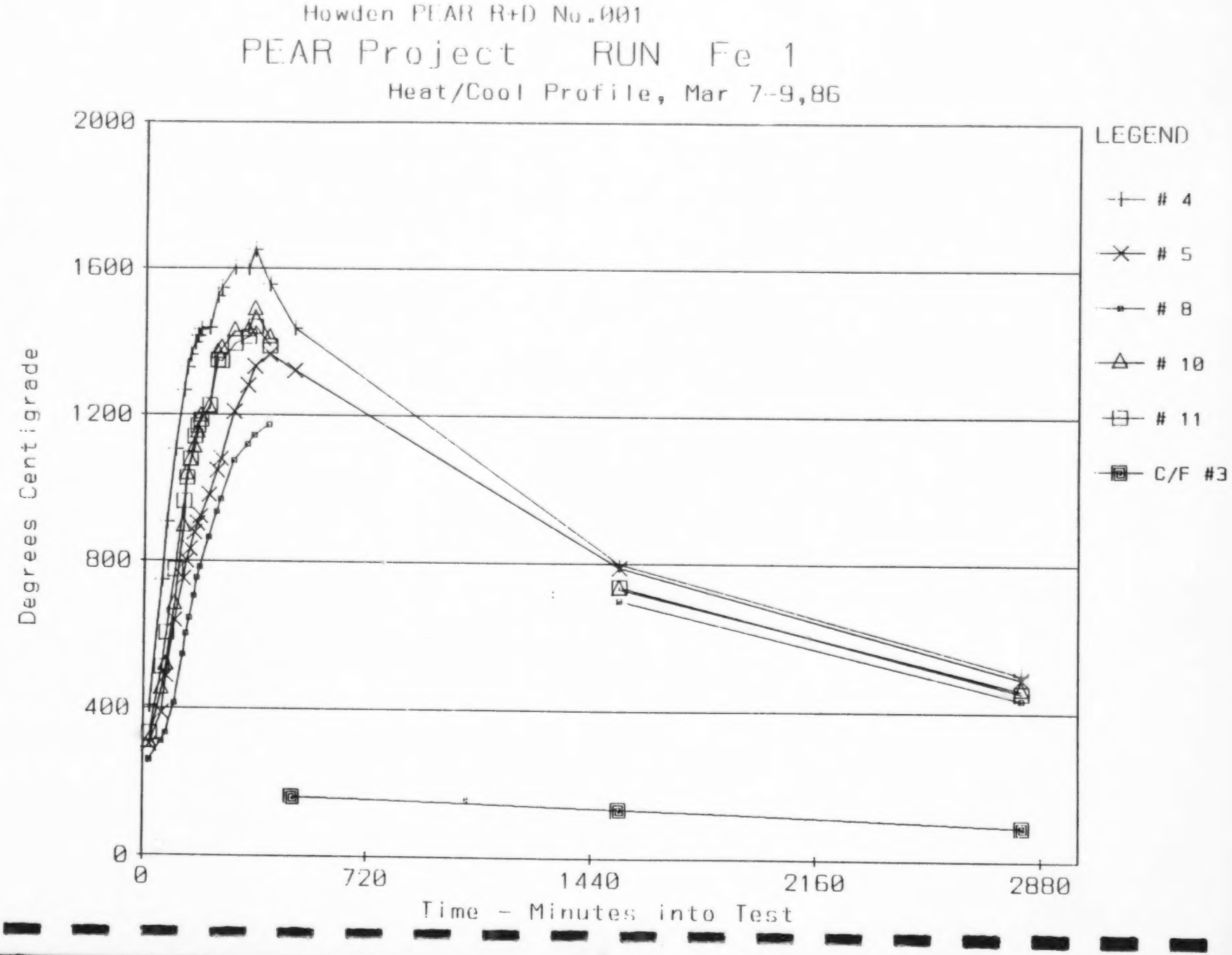
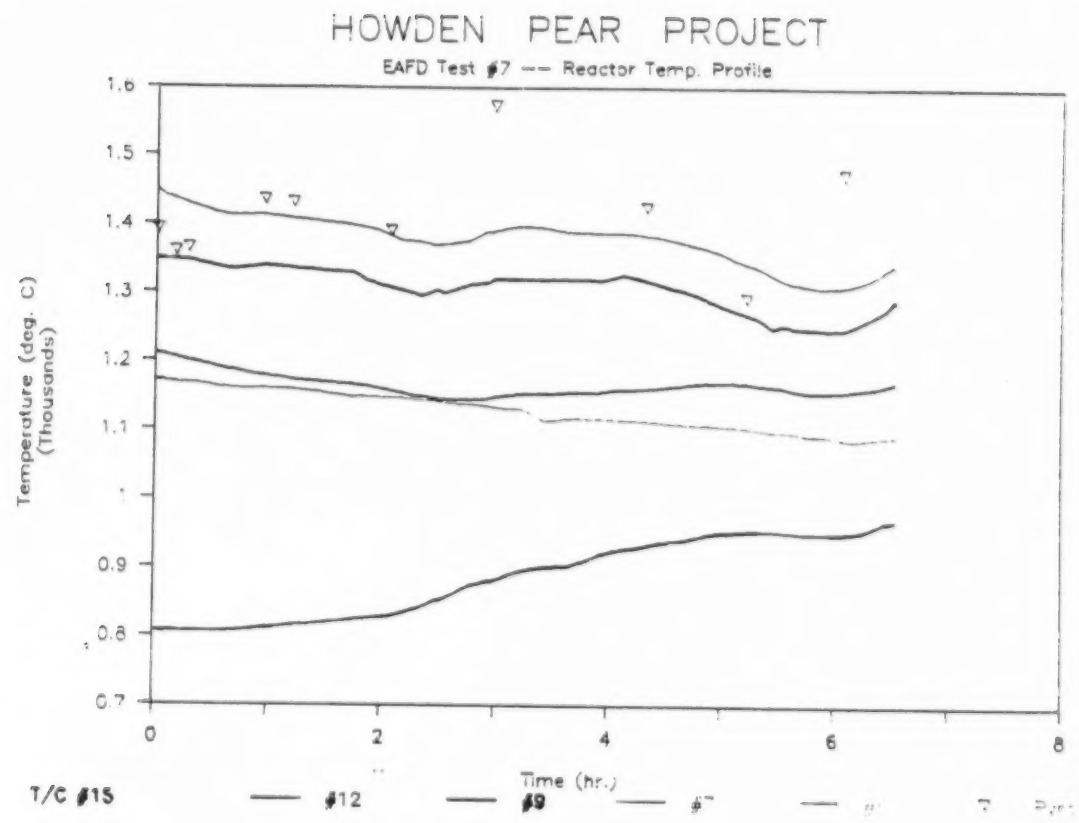

Howden PEAR R+D No.001
PEAR Project RUN Fe 1
Heat/Cool Profile, Mar 7-9,86
2000
1600
1200
800
400
0
Degrees Centigrade
0
720
1440
2160
2880
Time - Minutes into Test
LEGEND
4
5
8
10
11
C/F #3

FIGURE 6


HOWDEN PEAR PROJECT
EAFD Test #7 -- Reactor Temp. Profile
Temperature (deg. C)
(Thousands)
1.6
1.5
1.4
1.3
1.2
1.1
0.9
0.8
0.7
0
2
4
6
8
Time (hr.)
T/C #15
#12
#9

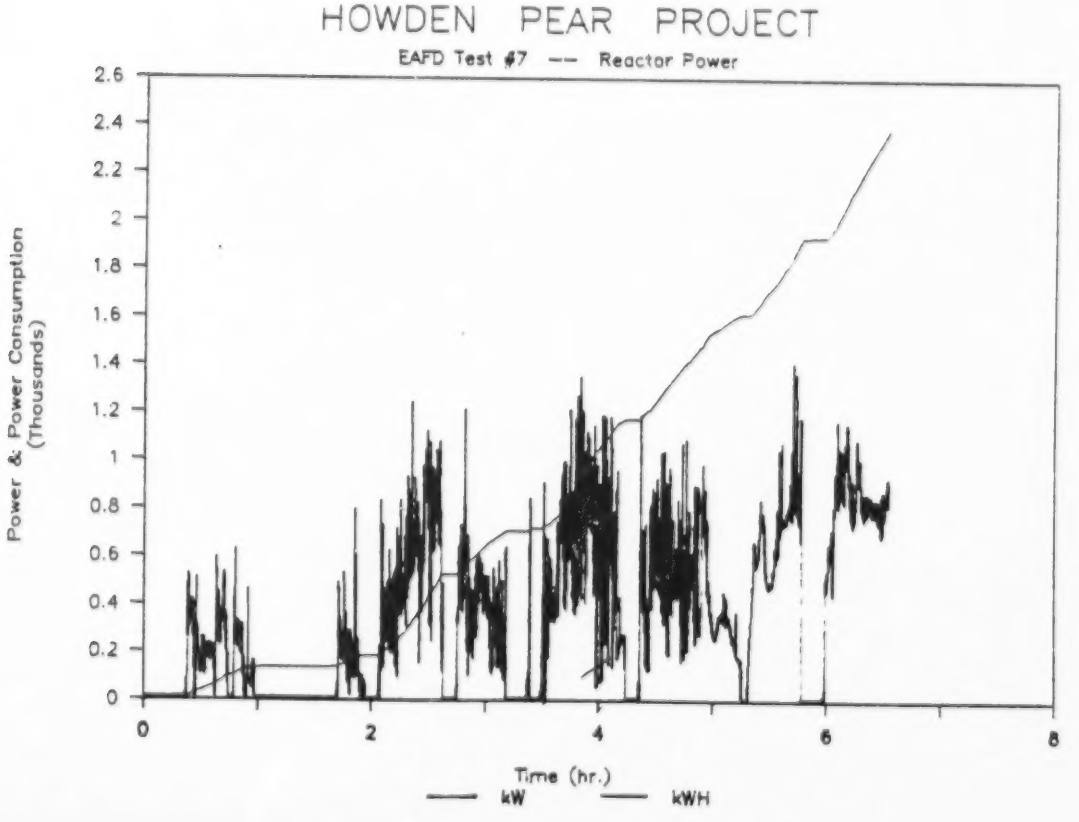
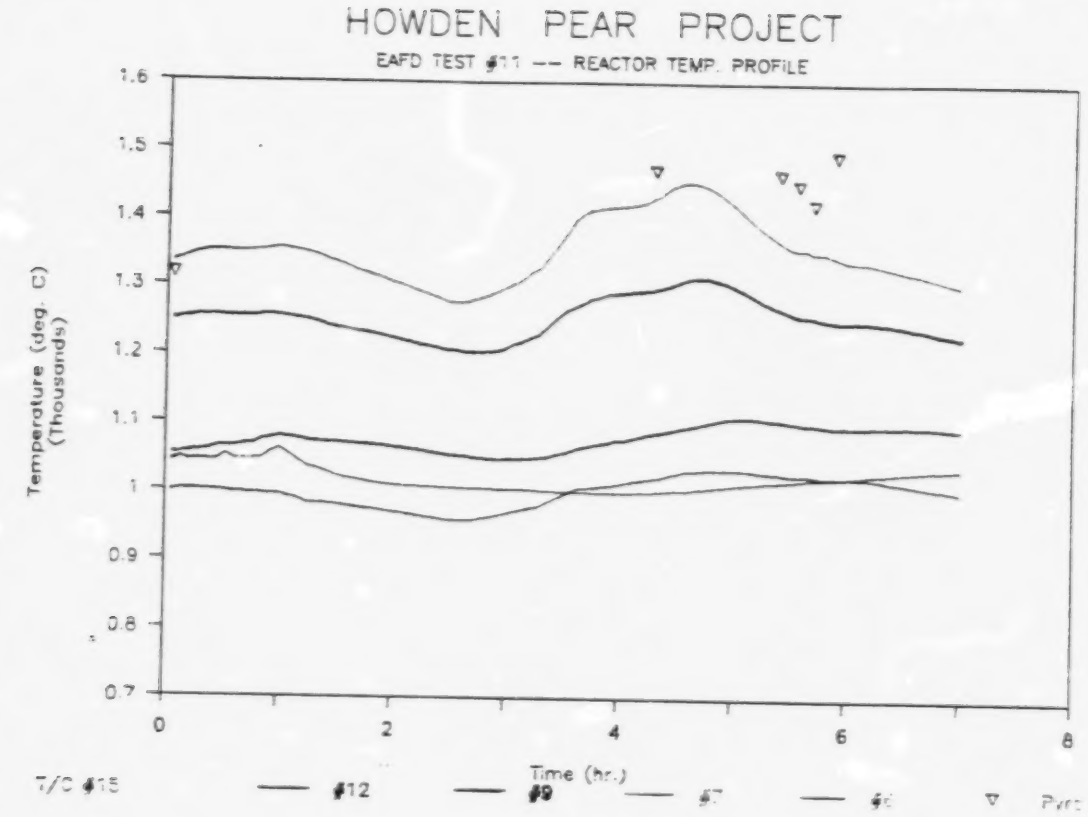

HOWDEN PEAR PROJECT
EAFD Test #7 -- Reactor Power
Power & Power Consumption
(Thousands)
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
2
4
6
8
Time (hr.)
kW
kWH

FIGURE 7


HOWDEN PEAR PROJECT
EAFD TEST #11 -- REACTOR TEMP. PROFILE
Temperature (deg. C)
(Thousands)
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0
2
4
6
8
Time (hr.)
T/C #12
T/C #9

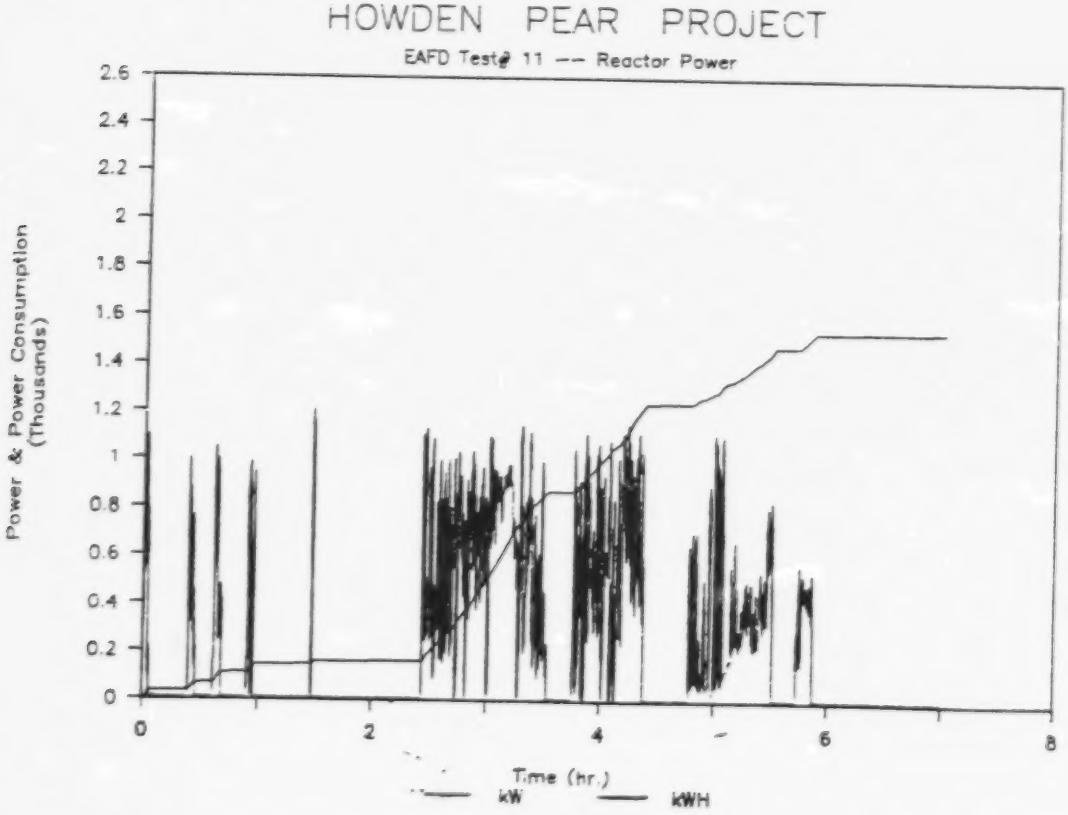
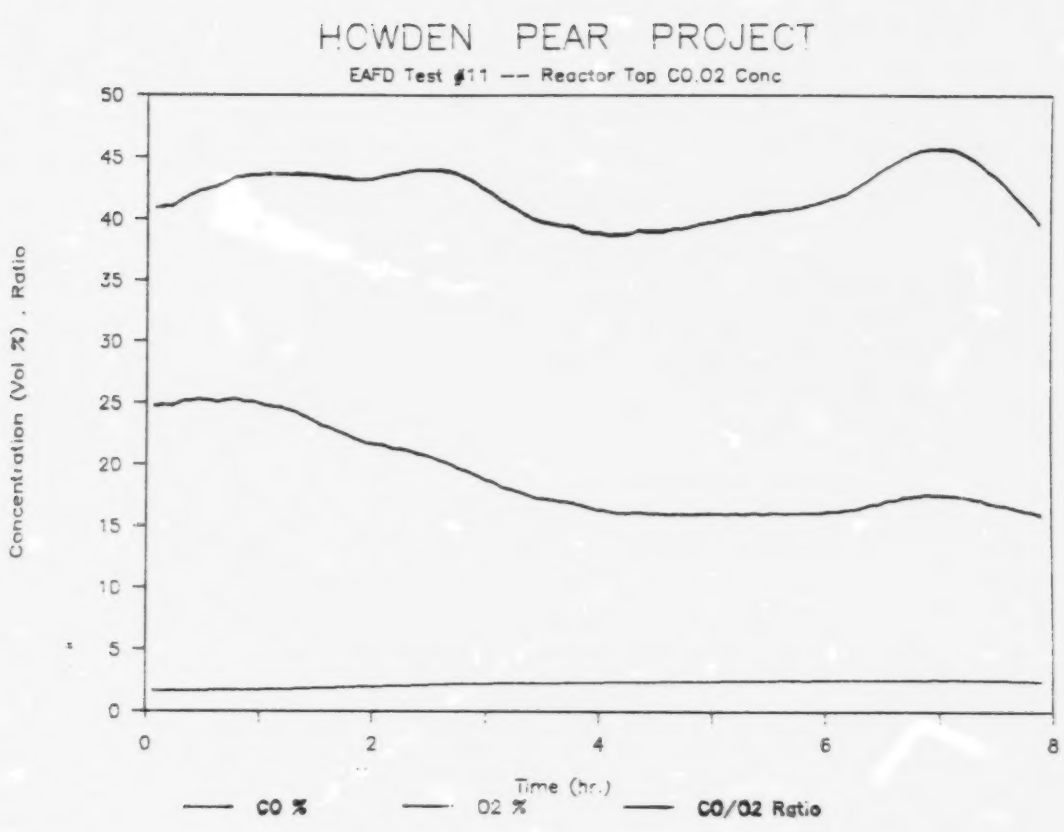

HOWDEN PEAR PROJECT
EAFD Test# 11 -- Reactor Power
Power & Power Consumption
(Thousands)
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
2
4
6
8
Time (hr.)
kW
kWH

FIGURE 8


HOWDEN PEAR PROJECT
EAFD Test #11 -- Reactor Top CO.O2 Conc
Concentration (Vol %) , Ratio
50
45
40
35
30
25
20
15
10
5
0
0
2
4
6
8
Time (hr.)
CO %
O2 %
CO/O2 Ratio

MILLIGRAM / LITRE EXTRACTED
Howden PEAR R+D No. 001
PEAR Project Flask Stability
Ontario Regulation No 309 Leachate Tests
LEGEND
Cadmium
Lead
Chromium
Zinc
CRITERIA Cd
CRITERIA Pb
CRITERIA Cr
Feed
Pb5
Pb6
Pb7
Pb8
Pb9
Pb10
Pb11
Pb12

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Paper Presented at
ELECTRIC ARC FURNACE DUST STUDY SESSION
Pittsburgh Airport
June 14, 1985

by

I. Howitt
Project Manager

PLASMA EXTENDED ARC REACTOR SYSTEM

The Tibur Plasma Extended Arc Reactor system was developed at the University of Toronto. The system has unique features which differentiate it from other plasma systems.

The overall arrangement of the Plasma Extended Arc Reactor system can be grouped into three sections - the reactor, the power supply and the control system.

The Reactor is a cylindrical steel shell lined with refractory material. A removeable disc type roof (equipped with a central feed port, an off-gas port and two observation ports) seals the reactor. Three hollow graphite electrodes are each supported on a moveable carriage mounted on the shell, allowing the electrodes to meet in the centre of the furnace or be withdrawn into the side-wall ports. The plasma gas (argon) is introduced through the central hole in the electrode. The electrodes are connected to the power supply cables through water-cooled contact blocks arranged for rapid replacement of the electrodes. The feed material is conveyed to the reactor via a vibratory or screw feeder to the feed port and then by gravity passing through the plasma zone formed by the three electrodes into the molten bath. Off-gases are exhausted through the exhaust port. Molten metal is removed through the taphole.

The Power Supply utilized is three phase alternating current. A wide range of voltages and currents may be used to supply the reactor via a suitable transformer with secondary connections and on-load tap changer.

The Control System allows automatic or manual adjustment of the inter-electrode distance. Constant power input at any particular tap position can be achieved provided the electrodes are within the upper and lower position limits. Controls are provided to vary the material feed rate and meter the plasma gas rate. Display meters to monitor voltages, currents, power, etc. are provided. Computer control and data-logging systems can be provided to suit individual requirements.

In summary, the unique features of the Tibur Plasma Extended Arc Reactor are:

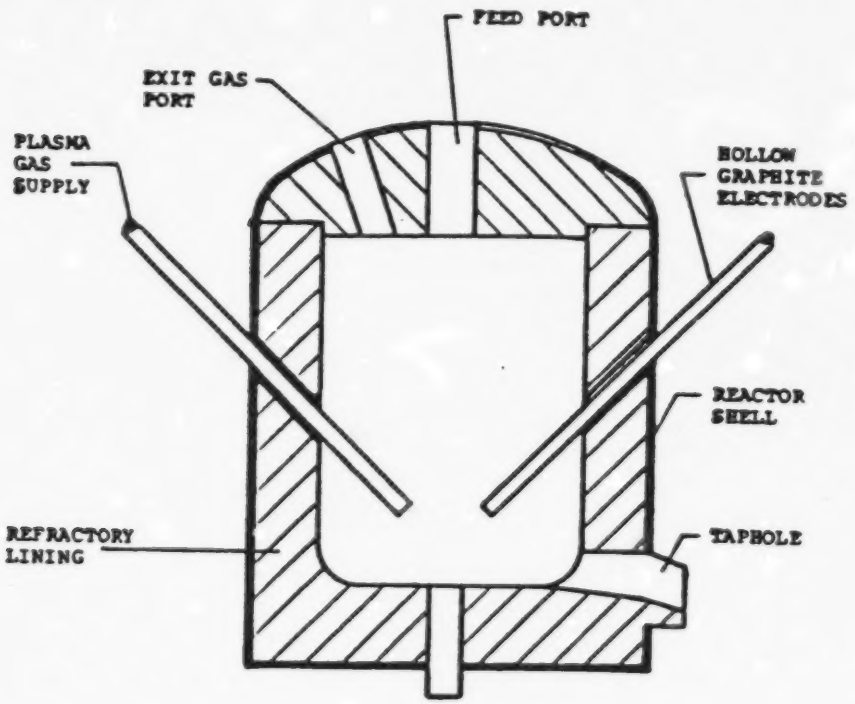
1. The unit operates on a standard AC mains electrical supply, where other systems in general use a DC supply requiring AC/DC convertor equipment in addition to the reactor transformer.

2. It uses graphite electrode technology familiar to the electric arc furnace operator. The electrodes are easily replaced. Carbon consumption is low, resulting in infrequent replacement. Plasma torches require frequent overhaul.

3. The plasma gas, usually argon, is introduced through a central hole in the carbon electrode which results in a stable arc with a low gas consumption.

4. The system operates efficiently in relatively small capacity units making it suitable for on-site treatment of electric arc furnace baghouse dust.

5. The unit is extremely quiet in operation.



TIBUR PLASMA EXTENDED ARC REACTOR

PEAR: THE TIBUR HOWDEN EXTENDED ARC REACTOR

C.B. Alcock*, A. McLean*,
I. Howitt**, J.W. MacDonald**

* Univ. of Toronto; Director, Tibur Howden Inc.
** Howden Group Canada Limited

This paper results from University/Industry collaboration: a desirable but difficult undertaking. The name of the Company carrying out the development at the industrial level is Tibur Howden (Tibur is an acronym meaning "Technical innovation by University research"). The Company which financed the laboratory studies, Tibur Metals, has transferred relevant technology to Howden Group Canada and the name "Tibur Howden" was adopted for the new venture. The device brought to industry from the laboratory is called a "Plasma Extended Arc Reactor" (PEAR). This paper describes most of the significant features of the PEAR development.

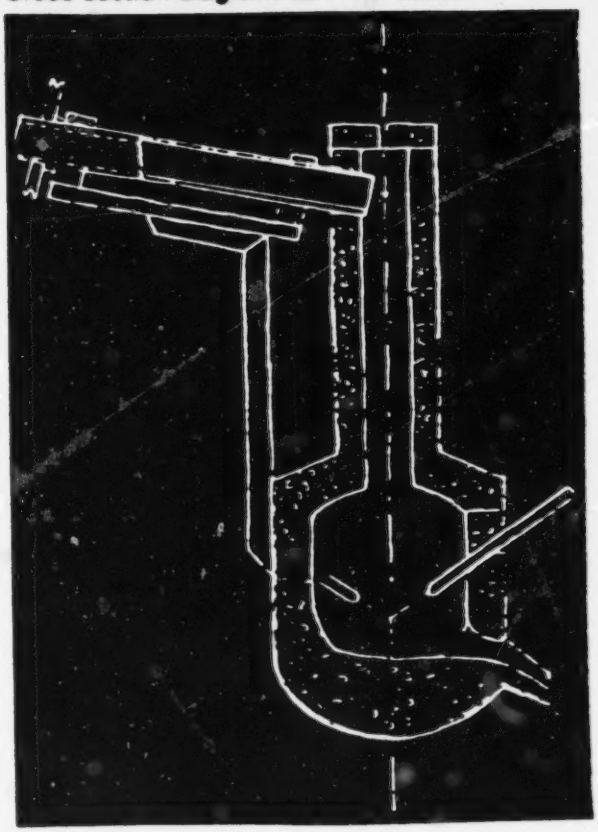
In the early 1970s a research team at the University of Toronto, decided that plasma technology had an important near-term future and that basic studies should be started in the application of this technology in extractive metallurgy. The study had to be carried out in laboratories at the University without significant government funding because plasma research was thought in the '70s to be too remote from practicality to merit support. The basic philosophy was based on the use of graphite electrodes because such practice is standard in industrial electric arc furnaces. Graphite electrodes are simple to make and easy to use and do not require water cooling. Plasma was generated in argon introduced through holes drilled along the electrode axes, and furnaces were operated at normal frequency, 60 Hz, and 110 AC voltage. The first Plasma Extended Arc Reactor was built using a modified Detroit rocking arc furnace (5KVA). In the literature the furnace was called "the Extended Arc Reactor" because of the lack of confidence which was generally held about the practicality of plasma research (Ref.1). Nowadays, after a successful period of studies spanning more than a decade, the term "plasma" is acceptable in metallurgy (Ref.2); hence, the Plasma Extended Arc Reactor (PEAR) (Table 1).

The first three-phase laboratory (25KVA) was principally used for the study of iron ore reduction. A mixture of iron ore, carbon and flux was introduced into a rotary preheater through a vibrating hopper (Fig.1). After

TABLE 1
Advantages of Plasma Operation

1. The electrical waveforms are more sinusoidal than in the normal arc furnace mode, leading to a higher power factor.
2. The arc can be extended, producing a more steady and diffuse heat source than in the normal mode.
3. The refractory lining lasts longer because the energy flux at the lining is more uniform.
4. The acoustic noise of the normal mode is practically eliminated.

FIGURE 1
Cross section diagram: 25 KVA reactor



passing through the pre-heater the material fell in free flight down a vertical column where reduction of the iron oxides was largely completed. The three graphite electrodes were introduced through holes in the side of the furnace body and the annulus around them was filled with high temperature wool to keep the furnace relatively gas tight. The gas leaving the plasma zone passed upwards through the flight tube and then the preheater before leaving the assembly, so counter-current heat exchange between the descending charge and the exiting gases was optimized.

The subsequent scale-up to the 100kW reactor again had graphite electrodes through the side, but now the wool was replaced with closed sliding holders in which the electrodes could be moved up and down by hydraulic actuators. By this means it was possible to extend electrodes to any length compatible with the furnace and at the same time air was excluded from the reactor. Current and voltage in each of the three electrodes were measured and a micro-processor system enabled the control of the power input to the furnace, since this mainly depended on arc length between the electrodes. The principles of such a small scale controller can, of course, be used on a 100 ton furnace equally as well as on a 100kW furnace.

During a period of collaboration with local industry in Canada, the behaviour of 60 ton scrap melting furnaces in the plasma mode was studied continuously over a period of several months. The electrodes showed no signs of thinning down at the tip and a cup formed around the point where the plasma gas flowed from the electrode passage (Fig.2). The introduction made it possible to control flare and reduce electrode consumption. The acoustical noise in the plant and the electrical noise going back into the power supply were both reduced very considerably (Ref.3).

In the laboratory the 100kW reactor was subsequently used principally to study the production of ferroalloys, such as ferro-chromium, ferromanganese and ferrovanadium from industrial waste products. All of these studies have been published in the technical literature (Ref.4,5,6). Because of its current industrial importance, the arc furnace dust problem was addressed. Arc dust reduction was carried out to liquid iron and slag, producing zinc and lead oxides from the gas off-take. The slags were quite acceptable from an environmental point of view (Ref.7) (Table 2).

At this point Howden Group Canada joined the team to enable further scale-up to 1MW and study of the processing of EAF dust on a scale of use to industry. A 1MW pilot reactor was constructed. The underlying principles adopted for scale-up were:

- The operation should be on-site using graphite electrodes coupled with standard arc furnace technology because the operators would be familiar with the

FIGURE 2

Electrodes from 60 ton furnace

TABLE 2
(100 KVA Reactor)

Typical results from baghouse dust study

Baghouse dust analysis:	13.8% Fe 1.61% Zn 0.25% Pb 24% SiO_2 25% C Balance Al_2O_3, MgO, MnO etc.
Charge:	43% dust 7% flyash 25% coke 25% lime
Product:	Metal < 0.001% Pb + Zn 1.6% C 3% Mn 14% Si Balance Fe Slag < 0.001% Pb + Zn
Flame condensate:	53% Zn 9% Pb

hardware, and the power supply would be readily available.

- The size of the furnace should match a typical steel plant requirement; it was thought that about 1MW would be satisfactory.

- Acceptable iron and slag should be produced in the furnace.

- Zinc and lead should be recovered separately as metals by condensation of the off-take gases.

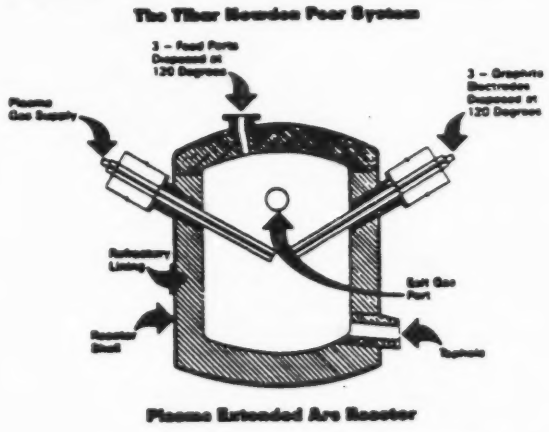
In certain respects, one can use the iron-making blast furnace as a model for the reduction of the oxides in EAF dust. At blast furnace metal temperatures, about 1400 degrees Centigrade, lead oxide, iron oxide and zinc oxide can be easily and directly reduced by carbon, while manganese and chromium oxides can be reduced into liquid iron when it is produced. If magnesium oxide is used as a lining to the furnace however, there is a danger it could be reduced to form magnesium gas at high temperature under these extremely reducing conditions. This would indicate that the choice of lining in a reactor using this basic chemistry should be graphite or possibly alumina-based.

The reduction of oxides by carbon at high temperatures will produce a mixture of CO and CO2. In these mixtures if there is 10% CO2 and 90% CO, iron oxide is fully reduced to iron, but it is necessary to approach 1000:1 CO to CO2 ratio in order to prevent re-oxidation of the zinc at the lower temperatures required for condensation, around 600 degrees Centigrade. Under blast furnace conditions, liquid iron saturated with carbon (the iron-carbon eutectic) is formed around 1150 degrees Centigrade, but it is necessary to reach 1350 degrees to make liquid slag. Hence the temperature of operation must reach 1400 degrees Centigrade to provide slag fluidity. In blast furnace operation iron has a low vapour pressure, lead has a high enough vapour pressure to be boiled off, manganese and chromium which would go into solution in the iron would not vaporize significantly, and zinc of course, is easily vaporized. The process for the treatment of EAF dust could therefore be carried out using a furnace lined with carbon, and limiting the upper temperature of the metal-slag system to 1550 degrees Centigrade, thus minimizing the electrical energy required to reach operating temperatures.

At this point, it should be remembered that an industrially useful reactor should theoretically be operated at about 1MW power level to process the EAF dust produced in a typical plant. Criteria for scale-up had to be based solely on experience gained from running a 100kW furnace (a 10:1 scale-up). The internal surface area was scaled up in proportion to the increase in energy input; this was so that the radiation flux through the walls would be constant in going from the small to the large scale while the power level was increased. This determined the diameter, and the volume was a result of using the same height to diameter ratio as in the 100kW unit. The electrode cross section was increased by changing from 30mm to a 130mm electrode diameter, allowing for 6000 amps maximum current. Some scale-up factors have only been discovered while running the 1MW furnace. For example, in the 100kW, 60 volts were used between electrode pairs, and this went up to 100 volts operating in the larger machine. The arc length increased from some 20 centimetres to about 3/4 of a metre and the argon flow rate went from 1 to 2 litres a minute up to 5 to 12 litres a minute.

In the present 1MW reactor, the aspect ratio, height/diameter, is about 1.4, and the electrodes can either be introduced at an angle of 15 degrees to the vertical, or 30 degrees to the horizontal. Material is fed in through the top of the shell and falls down through the plasma volume before being melted at the bottom. Exit gases go out through a port at the side and there is a taphole at the base for taking out the liquid iron and slag. The furnace lining is made of graphite bricks backed up with alumina (Fig.3).

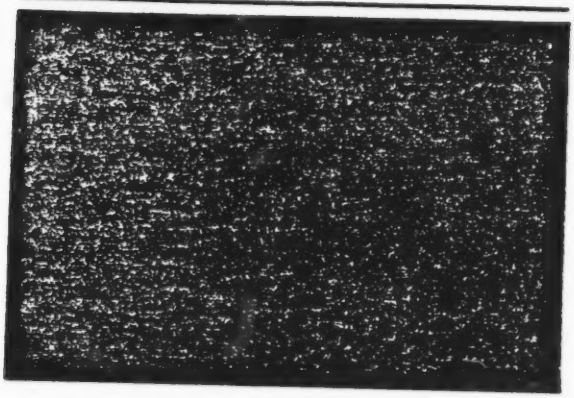
FIGURE 3


The Tibor Howdon Pear System
3 – Feed Ports Disposed at 120 Degrees
3 – Graphite Electrodes Disposed at 120 Degrees
Plasma Gas Supply
Refractory Lining
Exit Gas Port
Reactor Shell
Taphole
Plasma Extended Arc Reactor

At the start of a run the electrodes are brought together to initiate the plasma, but as the system warms up they can be pulled apart under control. The size of the plasma ball can be limited so as to protect the lining but it is possible to withdraw the electrodes practically back into the wall without arc extinction. When the furnace is cold, about 120V is required between electrodes, but this can be reduced to 80V after the furnace reaches operating temperature. Dust is introduced using briquettes, made from the dust, coal and the necessary flux for making blast furnace slag. This choice of input was made for the early trials so as to minimize the possibility of dust carryover into the zinc condenser. It is anticipated that the next step in development of the reactor will be direct

injection of dust into the plasma. Argon is injected through the electrodes to make the plasma, but it is possible to operate with nitrogen, CO or mixtures of all three gases. The exit gas is cleaned of particulates in a cyclone before passing to the condenser at about 900 degrees Centigrade. Zinc and lead are separated in the condenser, and slag and metal are collected at the taphole. Tibur Howden built the zinc condenser, mainly to a design provided by Imperial Smelting Processes Ltd. although some innovations were introduced (Fig.4).

FIGURE 4



The control system, used earlier for the 100kW furnace, has been augmented with data acquisition on the larger furnace. The whole control loop of the furnace is now being developed. Under ideal performance, of course, the service routines of the loop will control the furnace. A new approach to the control loop is to use an 'expert system' which has built-in 'know-how' which determines if the furnace is behaving in an abnormal manner, not conforming to the ideal of performance. The computer can then appeal to some semi-quantitative, qualitative or almost 'hunch' information which is fed to it as ancillary data. It can also refer to numerical data bases to get the necessary data to make further control calculations.

In the first design three electrodes were brought through the roof positioned at 120 degree angles when viewed in plan. In this the "vertical mode", the electrodes were actually 15 degrees from the vertical. The alternative, the "horizontal" mode, with electrodes actually 30 degrees up from the horizontal, was studied subsequently. A comparison between the two modes was made as part of the development program to address the problem of ladle heaters as well as EAF dust treatment.

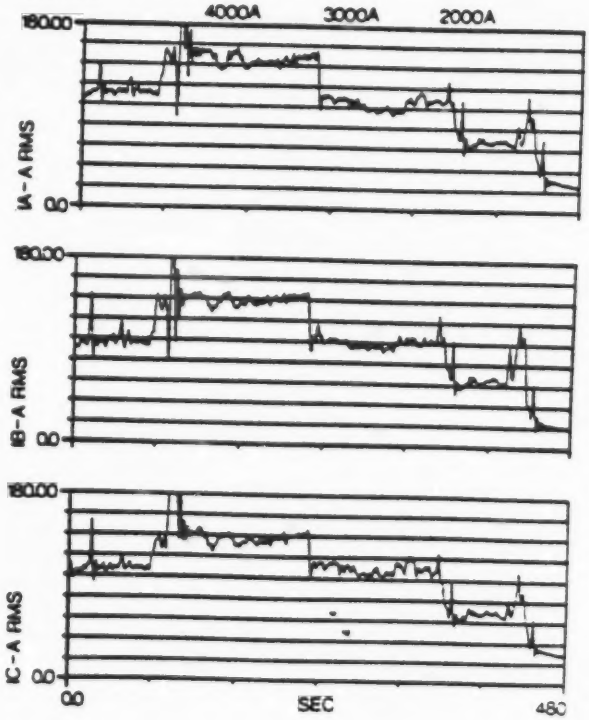
The furnace is presently being used in the horizontal mode to produce blast furnace type metal and slag, (blast furnace composition, 40/40 lime and silica, with balance being magnesia and alumina) in the furnace hearth, and liquid zinc and lead in the condenser. Suitable flux additions are made during the agglomeration of the EAF dust to obtain these products. The vertical electrode ports are now used for inspection to look inside the furnace during operation. The feeding system is split into three feeds which enter the reactor at positions between the electrodes. It is intended in the near future to make direct dust introduction into the furnace through nozzles. Experimentation has shown that large volumes of gas can be lanced into the reactor plasma volume without arc extinction.

The data are presented in the control cabin in two versions. There is direct on-line acquisition from some 16 thermocouples, placed strategically around the system to indicate how the temperature is distributed in the machine as well as what the levels are. A bar chart readout from many positions around the furnace is immediately available. Alternatively, the variation during a run at a few selected points can be seen. Voltage, current and power data are also acquired during the operation.

Ontario Hydro, the local electricity authority, measured the interaction between the system and the local power supply. The readings (Fig. 5) show the furnace being operated under manual control at three selected levels of power, 4000 amps, then down to 3000 amps. Variation in power level is achieved by changing the electrode spacing on-line. Since the length of the plasma column is the main resistance in the whole electrical system, it controls the power input to the furnace at these three levels. Under computer control these changes will be much more uniform.

FIGURE 5

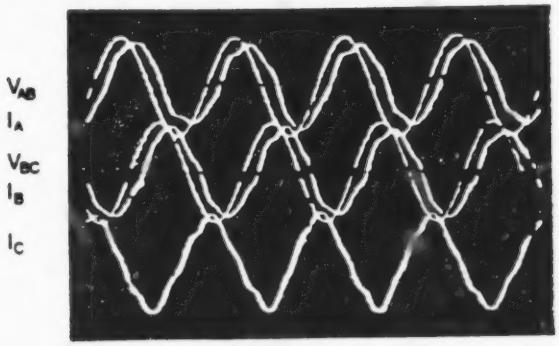
4-16KV Feeder Currents during the test period



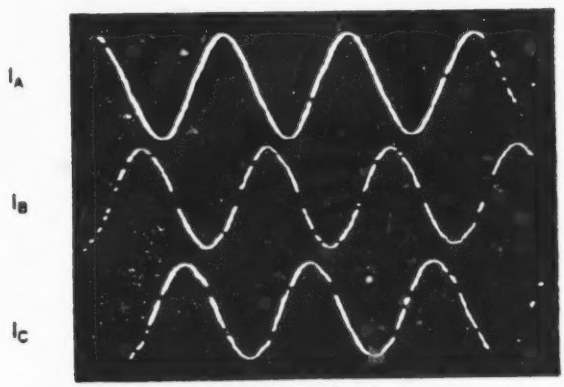
Waveforms that were taken from the furnace in operation show the same shape as was found in the 100kW furnace, and the 60 ton melting furnaces (Fig.6). The voltage waveform and the current waveform in this plasma operation are more nearly sinusoidal than is seen in the normal arc operation. This is because the voltage/time curve for normal operation looks almost like dielectric breakdown, which has a rather square shape. In plasma operation, the breakdown characteristic is eliminated and a more nearly sinusoidal form is achieved. Power factors in the plasma mode are higher than in the normal furnace arc, and were consistently over 0.9 from 100kW up to 25MW.

FIGURE 6

Typical 4.16KV Bus Voltage and Current Waveforms



Reactor at 0.7 MW, with feed

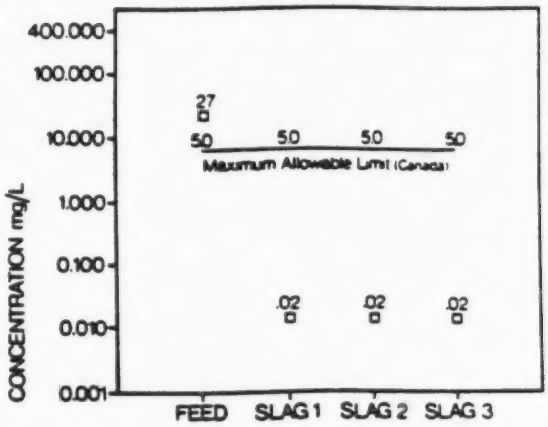


Reactor at 0.8 MW, with feed

The major objective has been to make products which are environmentally acceptable. Results in this respect from the 1MW reactor are very similar to those obtained in the 100kW study (Fig.7,8,9). The lead levels in the metal, slag, and slag leachate are very low indeed; probably acceptable for disposal as non toxic materials.

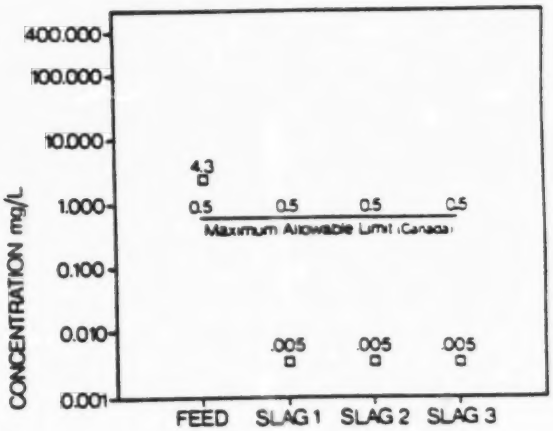
The furnace operates almost silently at the 1MW level, and so there are no problems from acoustic pollution.

FIGURE 7



Comparison of Leachate Extraction Tests showing actual lead concentrations (□) in feed material and slag products with the maximum allowable limit.

FIGURE 8



Comparison of Leachate Extraction Tests showing actual cadmium concentrations (□) in feed material and slag products with the maximum allowable limit.

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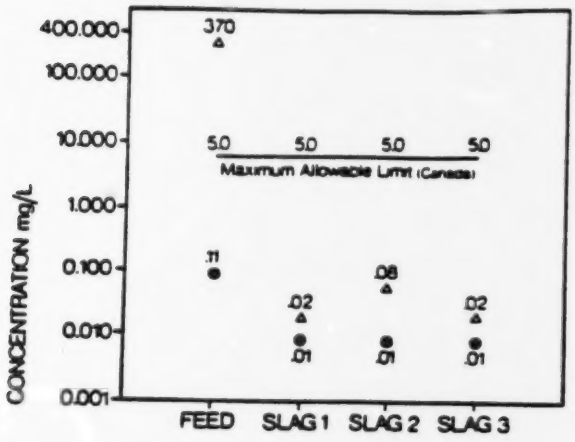
FIGURE 9



Comparison of Leachate Extraction Tests showing actual concentrations of zinc (△) and chromium (●) in feed material and slag products.

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